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LOW-TEMPERATURE CARBONIZATION OF COAL IN JAPAN

BY

WILLIAM T. REID

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

LOW-TEMPERATURE CARBONIZATION OF COAL IN JAPAN[1]

By William T. Reid[2]

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SUMMARY

Low-temperature carbonization of coal in Japan served as an important source of liquid fuels during the war. Six plants operating in Japan Proper produced 203,069 KL (53.7 million gallons) of liquid fuel from 1940 until the end of the war in August 1945, while four additional plants in Karafuto and Korea produced 211,943 KL (56.0 million gallons) for a total of 415,012 KL (109.7 million gallons) of liquid products.

Semicoke produced in these plants was used for domestic fuel, for gasification in portable gas producers on automotive vehicles, and to replace imported low-volatile bituminous coal in the manufacture of metallurgical coke. Since 1936 one plant had produced more than 300,000 metric tons of semicoke for blending with bituminous coal to form coke, while the total production of semicoke since the beginning of the industry in 1923 is approximately 2,000,000 metric tons. Despite an apparent annual carbonizing capacity of about 2,000,000 metric tons of coal for the entire country, the maximum amount of semicoke produced during the peak year, 1943, was 468,446 metric tons.

The equipment used is primarily of German design. Just before the end of the war, 6 plants using 20 Lurgi carbonizers were operating with a total rated capacity of more than 1,500,000 metric tons of coal per year, while 2 Koppers units had a combined annual rated capacity of 400,000 metric tons of coal. One plant using the Japanese-designed Mimura system was in service but with so much mechanical trouble that its output was small, while in another plant 4 Wanishi carbonizers of Japanese design but based on an early German development were running satisfactorily, and carbonizing about 100,000 metric tons of coal per year. A single installation of 15 American-designed Knowles ovens was operating near Tokyo but was carbonizing pitch for electrode carbon

No true low-temperature process used in Japan could carbonize strongly caking coals satisfactorily. The Mimura process designed for this purpose was unsuccessful, as was the Shimomura process before it, while the Lurgi, Koppers, and Wanishi systems operated only with noncaking or very weakly caking coals. The Knowles ovens, really a medium-temperature process, could carbonize caking coal without difficulty.

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War damage to these plants was severe. Only three were left in operating condition or were so slightly damaged that only minor repairs would be required to put them back into operation. More than half the capacity was in Karafuto and Korea and thus is no longer available for Japanese operation. The future status of most of the plants is uncertain, depending upon economic conditions within the country as well as control by the occupation forces.

ACKNOWLEDGMENTS

This investigation, made between April and August, 1946, was initiated by A. C. Fieldner, Chief, Fuels and Explosives Branch, Bureau of Mines, who early recognized the desirability of studying foreign developments in low-temperature carbonization as a guide to future trends in processing coal in this country. His enthusiastic encouragement and sage counsel were particularly helpful. Arrangements for temporary assignment as Scientific Consultant to the Supreme Commander of Allied Powers were made through T. A. Hendricks, of the Geological Survey, then acting as Chief, Mining & Geology Division, Natural Resources Section, GHQ, SCAP. The field investigations made in Japan were authorized by Lt. Col. Hubert G. Schenck, Chief, Natural Resources Section. The cheerful assistance of K. Asai, who served as an interpreter for this study both at headquarters and in the field, and who acted as a general guide and made many of the arrangements for plant visits under trying conditions, is gratefully acknowledged.

INTRODUCTION

Relationship with Synthetic-Liquid-Fuel Industry

Historical

The history of low-temperature carbonization in Japan in more recent years is connected closely with the production of synthetic liquid fuels. Although originally conceived by Dr. K. Shimomura in 1923 as a means of producing semicoke for use in blends for making metallurgical coke, low-temperature carbonization did not become commercially important until emphasis was placed on the value of the liquid products rather than on the semicoke.

Because of the almost insignificant occurrence of petroleum in the home islands, the Japanese Government began in 1923 to consider a national liquid-fuel policy in an attempt to make the country independent of foreign sources of supply. Not until 1933, however, was any definite policy decided upon - that of encouraging the development of an industry for the low-temperature carbonization of coal and for increasing the production of shale oil at Fushun, Manchuria. In 1934 a subsidy was granted to encourage the construction of low-temperature carbonization plants; but industry was reluctant to accept it, and no progress was made. In July 1936 the Government expanded its objectives to include all means of producing substitute liquid fuels, and in August 1937 a 7-year plan was inaugurated. This included the Synthetic Oil Production Industry Law which was placed in force in January 1938 and the statutes creating the Imperial Fuel Development Co. (Teikoku Nenryo Kogyo K.K.), which became effective in September 1937. The institution of this Government-controlled

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company marked the first positive step towards achieving a national fuels policy which was satisfactory to the Japanese.

Production plan

The objective of the Synthetic Oil Production Industry Law, which was enforced simultaneously in Japan Proper, Korea, Karafuto, and Formosa, was to establish the liquid-fuel industry as rapidly as possible. To this end, Government assistance was limited to Bergius hydrogenation plants with a capacity of over 10,000 KL (2,642,000 gallons) per year, Fischer-Tropsch synthesis gas plants with a capacity of over 10,000 KL (2,642,000 gallons) per year, and low-temperature carbonization plants capable of processing more than 100,000 metric tons of coal per year. However, in 1941 these limits were abolished, and included were all plants producing fuel oil, lubricant, or crude oil of a hydrocarbon base from any raw materials except natural petroleum, the size limitations being restricted to a minimum of 1,000 KL (264,000 gallons) per year for aviation gasoline and lubricating oils, or 10,000 KL (2,642,000 gallons) per year of all other products. As an incentive, all companies complying with this law were exempted from payment of income tax, local tax, and import duty for equipment purchased abroad. At the same time, the privilege was granted of applying an expropriation law to obtain land for the plants, and a subsidy was allowed dependent upon the amount of liquid products actually made.

The law establishing the Imperial Fuel Development Co. provided that the company was entitled to carry on any business that would tend to promote the production of liquid fuels other than from petroleum. Original capitalization was ¥100,000,000 (the rate of exchange during 1940 and 1941 was approximately $0.23 per ¥) of which half was owned by the government with provision for an increase in capitalization only with Government approval; later the capitalization was expanded to ¥250,000,000. The president and vice-president of the company were appointed by the government, with a term of office of 5 years, and close governmental supervision of the company was retained. To make the investment attractive to other interests, the scope of the company was made extremely wide, permitting the manufacture and sale of the products, the managing of other business enterprises promoting synthetic-oil production, the ability to issue debentures up to five times the amount of the paid-up capital, a Government guarantee stabilizing the face value of the shares and the prompt payment of interest, the freedom from payment of dividends on shares held by the Government except when the profits exceeded 6 percent of the paid-up non-Government holdings, and the exemption from corporation and business taxation for 10 years. Obviously these concessions were made to attract capital to an undeveloped industry which probably would not be commercially successful on the basis of free enterprise, and it is doubtful if any other country could have made a more earnest attempt to promote favorable business conditions for an important new industry.

Subsidies and Costs

Government subsidies for the low-temperature carbonization industry began in 1934, when ¥10 per ton of tar produced was allowed in Japan Proper,

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while in Karafuto payment was based on the amount of coal carbonized, being ¥2 per ton. This subsidy rate was maintained until 1937, the amounts estimated and those actually paid being shown below:

Year	Subsidy for low-temperature carbonization	
	Estimated	Actually paid
1934	¥449,500	¥ -
1935	505,300	165,556
1936	552,000	287,092
1937	517,300	455,102
Total	¥2,024,100	¥907,750

It is interesting to note that, despite this relatively low subsidy level, amounting to approximately 0.9 cent per gallon of tar, almost half the estimated subsidy actually was paid, although the industry was in its infancy. Because the Synthetic Oil Production Industry Law went into effect in 1938, these subsidies were then changed, payments being based on the quantity of gasoline and of other liquid fuels produced. These new subsidies were as follows:

Year	Subsidies paid for synthetic gasoline, ¥ per ton		
	Hydrogenation	Fischer-Tropsch	Low-temp. carbonization
1938...	0	0	43.88
1939...	77.00	66.00	47.00
1940...	72.00	60.00	39.00
1941...	72.00	60.00	39.00

Year	Subsidies paid for other liquid fuels, ¥ per ton		
	Hydrogenation	Fischer-Tropsch	Low-temp. carbonization
1938...	0	0	17.20
1939...	34.00	47.00	18.00
1940...	24.00	50.00	13.00
1941...	24.00	50.00	13.00

The more successful operation of the low-temperature carbonization plants is indicated by their lower average subsidy level, being for gasoline 57 percent and 68 percent, respectively, of that for the hydrogenation and Fischer-Tropsch processes. For other liquid fuels than gasoline the contrast is more striking, low-temperature carbonization receiving on the average only 36 percent of the subsidy for hydrogenation and 31 percent of that for the Fischer-Tropsch process.

In 1942, following the start of the war, these direct-subsidy payments were abolished, and complete control of the industry was taken over by the Government. This control consisted largely of fixing prices, all liquid fuels being purchased by the Government-controlled Sekiyu Kyohan Kogyo K.K. and in turn sold at fixed prices to the ultimate consumer. Besides furnishing a centralized pool for handling all liquid fuels, including those from petroleum, this also served as a ready means of rationing liquid fuels for necessary nonmilitary purposes. Purchase prices and official selling prices of various liquid fuels during the war years were as follows:

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Material	Process	Purchase price, ¥ per KL	Equivalent purchase price, cents/gal.*	Official selling price, ¥ per KL	Equivalent selling price, cents/gal.*
Aviation gasoline	Hydrogenation	600	52.2	444	38.7
Motor gasoline	do.	400	34.8	307	26.7
Gas oil	Fischer-Tropsch	340	29.6	177	15.4
Semi-Diesel oil	Low-temp. carb.	180	15.7	88	7.7
Bunker fuel oil	do.	100	8.7	84	7.3

*At $0.23/Yen.

The lowest mark-down between purchase price and official selling price was for bunker fuel oil from the low-temperature carbonization processes. As will be shown later, this was the primary liquid product obtained from these plants, amounting to more than half of all liquid fuels they produced.

In order to meet the difference between operating cost and revenue for the Imperial Fuel Development Co., it was necessary also to grant it yearly subsidies in addition to those paid independent operating companies. The extent of these annual payments is shown below:

Year	Subsidy for Imperial Fuel Development Co.
1937	¥ 148,094
1938	878,387
1939	1,938,000
1940	2,625,057
1941	4,086,052
1942	4,050,650
1943	7,497,335.
1944	8,519,288.

The total subsidy allowed this organization thus exceeded ¥29 million. At a average exchange rate of 23 cents, this would be equivalent approximately to $6.7 million American. For the period from 1940 to 1944, inclusive, when 430,116 KL (113.6 million gallons) of liquid fuel was produced, the subsidy therefore averaged ¥69 per KL, or about 6 cents per gallon. It should be realized that this payment covered only the difference between expenses and revenue for this one company and that the total subsidy for the industry was much greater. How much greater is difficult to estimate because of the changing basis of payment.

Statements of costs incurred under war conditions usually have little significance; but it is evident that in Japan, the production of synthetic liquid fuels was not commercially successful, despite the high cost of imported petroleum. Even the low-temperature carbonization processes, although more nearly self-sufficient financially, were not able to operate at a profi

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Quantity of Liquid Fuels Produced

As already noted, the production of liquid fuels from coal at a cost lower than that of other processes was the principal stimulant to the installation of a large, low-temperature carbonization industry in Japan. The growth of the industry is shown in table 1, which also indicates the negligible amount of liquid products obtained from hydrogenation and the small amount from the Fischer-Tropsch process, resulting from the inability of Japanese chemists and engineers to operate the plants successfully. Actually, for the period 1940 to 1945, low-temperature carbonization produced seven times as much liquid products as the combined synthetic liquid fuels industry. During the same period, assuming a 75-percent yield of refined fuel products from the crude oil produced in Japan proper, liquid fuels from low-temperature carbonization amounted to 33 percent of that obtained from domestic petroleum. A comparison between the quantity of liquid fuels from coal and the production of crude petroleum is shown in table 2.

TABLE 1. - Liquid fuels from coal, total production

Process	Total production, KL, Fiscal year 1/						
	1940	1941	1942	1943	1944	1945	Total
Low-temperature carbonization:							
Japan Proper	14,331	26,099	38,304	53,430	56,491	14,414	203,069
Karafuto	8,783	14,003	15,328	25,044	45,941	19,607	128,706
Korea	9,840	14,600	24,304	18,021	10,772	5,700	83,237
Total	32,954	54,702	77,936	96,495	113,204	39,721	415,012
Fischer-Tropsch:							
Japan Proper 2/	1,888	7,202	10,844	15,673	17,806	4,198	57,611
Hydrogenation:							
Manchuria 3/	0	0	720	0	692	0	1,412
	Total production, thousands of gallons						
Low-temperature carbonization:							
Japan Proper	3,786	6,895	10,119	14,115	14,924	3,808	53,647
Karafuto	2,320	3,699	4,049	6,616	12,137	5,180	34,001
Korea	2,600	3,857	6,421	4,761	2,846	1,506	21,991
Total	8,706	14,451	20,589	25,492	29,907	10,494	109,639
Fischer-Tropsch:							
Japan Proper 2/	499	1,902	2,865	4,140	4,704	1,109	15,219
Hydrogenation:							
Manchuria 3/	0	0	190	0	183	0	373

1/ Fiscal year, Apr. 1-Mar. 31.
2/ No stated production outside Japan Proper.
3/ No stated production except in Manchuria.
Source: Teikoku Nenryo Kogyo K.K.

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TABLE 2. - Comparison between liquid fuels from coal and production of crude petroleum

Fiscal year1/	Refined products: Low-temperature carbonization2/ KL	Low-temperature carbonization2/ Thousands of gal.	Fischer-Tropsch KL	Fischer-Tropsch Thousands of gal.	Hydrogenation KL	Hydrogenation Thousands of gal.	Crude-oil production, Japan Proper KL	Crude-oil production, Japan Proper Thousands of gal.
1940...	32,954	8,706	1,888	499	0	0	334,834	88,456
1941...	54,702	14,451	7,202	1,903	0	0	316,658	83,655
1942...	77,936	20,589	10,844	2,865	720	190	269,354	71,158
1943...	96,495	25,492	15,673	4,140	0	0	268,397	70,905
1944...	113,204	29,906	17,806	4,704	692	183	262,157	69,257
1945...	39,721	10,493	4,198	1,109	0	0	235,704	62,268
Total	415,012	109,637	57,611	15,220	1,412	373	1,687,104	445,699

1/ Fiscal year, Apr. 1-Mar. 31.
2/ Japan Proper, Karafuto, and Korea.
Source: Teikoku Nenryo Kogyo K.K. and Mining Bureau, Department of Commerce and Industry.

Present Status

After the disastrous end of the war, the Japanese Government abolished the Synthetic Oil Production Industry Law and stated that no longer would any financial assistance be granted the synthetic-fuel industry. In an attempt to realize as much as possible of their investment, the larger companies made plans to convert those plants not completely destroyed by bombing, so that they could produce ammonium sulfate to be used as fertilizer. The low-temperature carbonization plant of Nissan Ekitai Nenryo Kogyo K.K. at Wakamatsu, which was only slightly damaged, was rapidly restored to service, and its four Lurgi carbonizers thus were available as a source of semicoke and liquid fuels. The Lurgi carbonizers at Ube, however, were badly damaged and probably will be scrapped, although the Koppers continuous vertical ovens were being considered for rebuilding. Low-temperature carbonization and synthetic-fuel plants alike in northern Korea, Manchuria, and Karafuto, being under Russian control, have been considered permanently lost by the Japanese, with the result that they are no longer existent so far as future policy is concerned.

Large-scale operation of the synthetic-liquid-fuel plants which remained standing in Japan Proper has been impossible because of an unparalleled shortage of coal, and at the end of the first year of occupation none of these plants were operating. Complete disruption of the country's finances leaves the future status of most of the plants indistinct; the low-temperature carbonization plants visited were examined with this point in mind, and the probable future policy is described later for each.

Scope of Report

The objective of this report is to give in considerable detail the operating factors relating to the performance of low-temperature carbonization processes and to show the extent of the industry in Japan. Although all of

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the carbonization processes operating successfully were known prior to the war, little information was available on their performance. The experience gained by the Japanese during the past 5 years and reported here will permit evaluation of the suitability of these processes in the United States for the production of smokeless solid fuel. Also, since liquid fuels are an important product of these plants, their production in Japan far exceeding that of synthetic-liquid-fuels plants designed particularly for this purpose; any consideration of future liquid-fuels policy for Japan should consider that produced from coal by low-temperature carbonization methods.

The data on which this report is based were obtained by visiting each plant understood to have operated a low-temperature carbonization process. For those plants in which the equipment was already dismantled, an attempt was made to see any apparatus still remaining, and the operation of the plant was discussed with the engineers who could describe its performance best. Many of the production data at some plants had been destroyed during fires resulting from incendiary raids, in which case data were sought from Teikoku Nenryo Kogyo K.K. Since this company had direct control of the entire industry, information supplied by it was considered reliable.

Units Used

Throughout this report the units used are those common in Japan, and the ones in which the statistics were originally reported. Weights are expressed in metric tons, shortened to ton, and liquid products in kiloliters, KL. Gas volumes are in cubic feet at 0°C. and 760 mm. pressure. Conversion of these units to others likely to be desired can be made as follows:

Unit	Multiply by	Result
Metric ton	2,205	Pounds
Do.	1.1023	Short ton
Kiloliter	6.29	Barrels
Do.	264.2	U. S. gallons
Cubic feet, 0° C. and 760 mm. Hg	1.054	Cubic feet, 60° F. and 30 inches Hg
Cubic meters	35.3	Cubic feet

For the convenience of the reader, temperature values in °F have been inserted after those in °C; similarly, equivalent gallon values have been inserted after volumes reported as KL's.

LOW-TEMPERATURE CARBONIZATION PROCESSES

Definition

Low-temperature carbonization is the physical process of removing a part of the volatile matter in coal by the application of heat in the absence of air, the temperature being restricted to the range 500° to 700° C. (932° to 1,292° F.) to prevent as far as possible thermal decomposition of the hydrocarbons evolved. The solid product remaining is termed "coalite" in Japan but more properly is called "semicoke" if made from a weakly caking coal, or

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"char" if made from a noncaking coal. For the purpose of simplicity, the product will be referred to as "semicoke" in this report. It is much more reactive than high-temperature coke, while the coal-tar contains more light fractions than that obtained from high-temperature processes. Because thermal decomposition, or "cracking", of the tar is slight, the amount of liquid products obtained is two to three times greater than when the same coal is carbonized at 1,000° to 1,200° C. (1,832° to 2,192° F.) as in usual coke-oven practice. At the same time, the gas yield is less, but the calorific value of the gas usually is higher unless it is diluted with the products of combustion sometimes used for internal heating of the coal in the carbonizer.

Use of Products

The principal uses of semicoke are for (1) domestic fuel, where its reactivity and smokeless nature are particularly desirable, (2) commercial gasification processes such as gas producers and water-gas generators requiring a free-burning fuel, (3) portable gas producers on automotive vehicles where it substitutes for charcoal, and (4) blending with high-volatile bituminous coal to replace all or part of the low-volatile bituminous coal commonly used in the manufacture of coke of metallurgical grade. Semicoke generally is too friable for use by itself as a metallurgical fuel, as in blast furnaces, and is too reactive for such purposes.

Low-temperature tar usually is refined directly for the production of liquid fuels, including motor gasoline, semi-Diesel oil, and bunker fuel oil; the gas oil sometimes obtained also may be used as a liquid fuel since it is similar in boiling range to kerosine. Hydrogenation of low-temperature tar is simpler than the direct hydrogenation of coal; thus the tar also may serve indirectly as a source of synthetic liquid fuels. Because low-temperature tar is rich in tar acids, it serves as an important source of creosote for use as a wood preservative and also as a source of phenol and cresol. By suitable refining processes, other products also can be recovered, including paraffin, naphthalene, and xylenol.

Description of Processes Used

General

Six distinct types of equipment have been used in Japan for the carbonization of coal at temperatures lower than 1,000° C. Although the temperature of the heating surface in some of these methods may be higher than the range of 500° to 700° C. (932° to 1,292° F.) usually considered as low-temperature carbonization, they have been included in this study because of the increased yield of liquid products obtained or the highly reactive nature of the semicoke produced. So-called "medium-temperature" processes, for purposes of simplification, are considered more properly to belong in the general class of low-temperature carbonization methods, as opposed to the usual vertical-slot oven operating at high temperatures primarily for the production of metallurgical coke.

The six types and their individual features are as follows:

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Types of low-temperature carbonization processes in Japan

Name	Type of retort	Method of heating	Internal agitation	Carbonizing temperature, °C.	Carbonizing temperature, °F.	Output
Lurgi	Vertical, stationary	Internal	None	600	1,112	Continuous.
Koppers	Vertical slot, stationary	External and internal	do.	700-850	1,292-1,562	Do.
Mimura	Horizontal, rotating	External	Intermittent	500	932	Do.
Shimomura	Horizontal, stationary	do.	Continuous, high speed	500	932	Do.
Wanishi	Horizontal, rotating	do.	None	500	1,022	Do.
Knowles	Horizontal, sole oven	do.	do.	1,150	2,102	Intermittent.

A brief description of the features of each of these processes is included in this section, while more detailed information on the performance of the equipment and the amount and quality of products obtained is given in the discussion of each plant.

Lurgi

The Lurgi "Spulgas" system has been one of the most successful of the more than several hundred patented processes for the low-temperature carbonization of coal. In 1939, 18 Lurgi plants were operating throughout the world, with an estimated total daily capacity of 42,000 tons of coal, equivalent to 140 units each rated at 300 tons per day.

A single unit consists of two parallel, identical, rectangular, vertical shafts, each shaft being independent of the other except for common burners supplying the heated gases for drying and for carbonizing the charge and for common gas inlet and offtake mains. The raw coal enters at the top and passes by gravity through three superimposed sections; in the upper it is heated to 250° C. (482° F.) for drying, in the carbonizing zone its temperature is increased to approximately 600° C. (1,112° F.), and finally in the last zone it is cooled to 100° C. (212° F.) before the semicoke is discharged. Heat transfer in each zone is accomplished by circulating large volumes of gas, the process thus being one of internal heating.

Because of the necessity of recirculating gas, the gas-purifying and tar-removal system is an accessory part of the equipment. The volatile products from the carbonizing zone are led first to a precooler, where tar having a

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softening point higher than 40° C. (104° F.) is condensed, thence to a Cottrell precipitator, where the tar mist and dust is removed. The gas then passes through two water-cooled towers where additional tar is condensed, through a gas blower to a last cooling tower, and finally to an oil scrubber where the light fractions are removed. The purified cold gas from the scrubber returns to the carbonizer, where a large proportion enters the cooling zone and a part is burned to supply the heat necessary for the process. Excess gas is withdrawn from the system after the scrubber and is used as a fuel gas for steam generation or other heating applications. Further details of the process are included later in the description of the Nissan Ekitai Nenryo plant at Wakamatsu, Fukuoka-ken.

Koppers

The design of the carbonizing section of the continuous vertical Koppers ovens, intended primarily for the production of coal tar and synthesis gas, is similar to that of German Koppers high-temperature ovens. Heat generated by burning gas in flues of silica brick is transferred to the charge by conduction from the hot brick walls, the difference from usual practice consisting in the movement of the coal continuously downward rather than being charged intermittently and pushed horizontally at relatively long time intervals. Also, the coal used must be noncaking, for no provision is made for mechanically removing the semicoke formed. Large quantities of steam added below the carbonizing zone in the continuous oven also is a point of difference, the resulting water gas not only increasing the gas yield but, in conjunction with the undecomposed steam, serving to augment the transfer of heat to the charge. The method, therefore, is a combination of external and internal heating.

Because the temperature in the flues ranges from about 1,000°C.(1,832°F.) at the bottom to 850° C. (1,562° F.) at the top, the process is generally termed "medium-temperature" carbonization by the operators, as the estimated maximum temperature of the charge may be 800° C. (1,472° F.). Some thermal decomposition of the tar vapors is certain to result from contact with the hot walls, therefore the tar yield would be less than with internally heated processes having the same carbonizing temperature.

Since the yield of gas from these ovens is large, they are usually employed in applications where synthesis gas is required; heating of the flues in such cases is done with producer gas generated from a part of the semicoke obtained. Coal tar is recovered from the gas by conventional means.

Mimura

Designed in 1938 by S. Mimura of the Tokyo Gasu K.K., this process was intended originally as a source of low-temperature tar for hydrogenation to produce liquid fuels. Strongly caking bituminous coals were used because the yield of tar was expected to be greater than with noncaking coals, and the resulting semicoke would be more reactive. The externally heated rotating horizontal cylindrical retort with counter-rotating, oscillating rabble arms is similar in principle to types developed in other countries, but the arrangement of mechanical equipment for driving the moving parts in unusually complex.

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The retorts are constructed of mild-steel plates by forming and welding and are 25-1/2 feet long and 25 inches inside diameter. Agitation of the charge is obtained by slowly rotating the internal rabble arms intermittently and by moving them horizontally lengthwise through the forming semicoke. The charge is moved through the retort during the forward stroke of the agitator by blades in one plane at right angles to the concentric central shaft. On the return stroke the agitator is rotated so that the blades are withdrawn from the charge and pins making up the remainder of the circumference of the shaft are dragged through the plastic coal. Together with the continuous rotation of the retort, this agitation increases the rate of heat transfer and is intended to decrease the tendency of the coal to form large masses of sticky material, thus minimizing adherence of semicoke to the walls of the retort.

The retorts are mounted three high in batteries of 24, each group of 3 retorts being heated in an individually gas-fired refractory furnace. Regenerators are provided but are not used. The temperature of the steel shell of the retort generally is maintained at 550° C. (1,022° F.), but the temperature of carbonization is 500° C. (932° F.).

Tar recovery and processing is done by the usual equipment of byproduct coke plants.

Shimamura

This process by K. Shimamura, patented in Japan in 1923 as No. 50,532, was for the purpose of furnishing semicoke for blending with high-volatile bituminous coal to produce a blocky coke suitable for foundry or metallurgical purposes. It uses externally heated horizontal, cylindrical, stationary cast-iron retorts, generally arranged in pairs one above the other, each pair constituting one set. Each set is enclosed in a gas- or coke-fired refractory furnace for heating. The retorts usually are 12 feet long and 2 feet in diameter and have a rated capacity for each set of 8 tons of coal per day. The upper retort is fed with raw coal by a gastight screw conveyor; at the far end the partly carbonized charge passes through a vertical connecting pipe to the lower retort, and the final product leaves the set through a screw conveyor and water seal. The gas offtake is located at the junction point of the two retorts.

Each retort has a water-cooled, concentrically located, hollow shaft, externally driven, provided with rabble arms bent near their ends so as to propel the charge through the retort. Driven at 130-150 r.p.m., these arms serve as an attrition-type pulverizer and not only provide for lateral movement of the charge but are also intended to prevent it from agglomerating into large masses or sticking to the walls of the retort. Because of the crushing action resulting from the relatively high peripheral speed of the arms, the semicoke produced is in small, rounded particles, most of which will pass a 1/8-inch sieve. Temperature of the coal in the carbonizing zone usually is not higher than 500° C. (932° F.).

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Wanishi

Designed by M. Kawaguchi in 1936, this type of carbonizer uses an externally heated, rotating, horizontal, cylindrical retort without internal agitation. Movement of the charge through the retort is by a continuous internal spiral flange; thus it is a replica of the Thyssen retort developed in Germany prior to 1920. Each retort is 76 feet long and 7 feet 10 inches inside diameter, rotates at 0.28 r.p.m., and is mounted in an individual gas-fired furnace without recuperators. Because of the large size of the unit, and consequent high thermal losses, the quantity of gas used for heating purposes exceeds that obtained from the process, and it is necessary to use a supplementary source of gas. The temperature of the retort shell does not exceed 600° C. (1,112° F.), and the carbonizing temperature is about 550° C. (1,022° F.).

An inclined rotary drier, 73 feet long and 6 feet 4 inches inside diameter, dries the coal before carbonization and is internally heated by products of combustion withdrawn from the main heating chamber. It is connected to the carbonizer by a closed hopper and a rotary feeder, which prevents loss of byproducts. The drier rotates at 2 r.p.m.

The objective of this process is the production of semicoke to replace low-volatile bituminous coals for coke blends. Since such blending materials need not be in the larger sizes but instead are crushed before mixing, the use of noncaking coals for the production of small-size semicoke is justified. Dust in the offtake gases is minimized by the low velocity of the gases leaving the carbonizer and is removed by a hot, cyclone-type, dust collector. The process is not suitable for strongly caking coals.

Knowles

The Knowles ovens used in Japan are a duplicate of those in the United States and were constructed from plans furnished by an American engineering company. The method consists of heating a charge of coal on a horizontal refractory surface or "sole," which in turn is heated from beneath by gas burned with air preheated in a regenerator. Because the coal is not confined between two fixed refractory walls, as in the usual vertical-slot oven, expansion of the coal during coking causes no trouble. Also, because of rapid rate of heating of the coal charge, it is possible to produce a satisfactory grade of coke from coals normally considered poorly coking in slot ovens.

Fifteen ovens usually are constructed in one battery. Each oven is 9 feet 9 inches wide and 40 feet long, with a longitudinal arch having a 6-foot radius and a rise of 2 feet 5 inches. The height from the floor to the springline is 1 foot 10 inches, but the maximum depth of coal charged is 12 inches. Coal is dropped from the top of the ovens through eight charging holes uniformly spaced in pairs along the length of the oven and is leveled by a mechanical arm operated from the pushing machine. The carbonized charge is removed by a pusher of usual design running on widely spaced rails parallel to the battery. The gas and tar evolved from the charge are removed through a single offtake pipe in the crown of the arch near the end of the oven.

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Although the flue temperature may be as high as 1,250° C. (2,282°F.) and the floor tile surface 1,150° C. (2,102° F.), there is little thermal decomposition of the tar, since most of it passes upward through the cold charge of coal and escapes without coming in contact with heating surfaces. Thus, the tar yield is greater than in vertical ovens where much of the tar-laden gases comes into contact with the hot refractory walls. Since the resulting product is a mixture of high-temperature coke from the portion of the charge resting directly on the heated floor and low-temperature semicoke from that in the upper part of the charge, the ratio depending upon the duration of the coking period, the process is generally considered as medium-temperature carbonization.

LOCATION OF PLANTS

Japan Proper

Eight commercial-size plants for the low-temperature carbonization of coal have been operated in Japan Proper; their location is shown in table 3, with one in Kyushu, six in Honshu, and one in Hokkaido. The first of these plants was built in 1923 but was small in size and was dismantled in 1930 because of mechanical shortcomings. Two others were built prior to 1940, but not until wartime shortages of liquid fuels became imminent and importation of petroleum stopped did construction reach its peak. During the period October 1940 to November 1943, five plants were placed in service with a total rated capacity of 1,270,000 tons of coal per year. The actual maximum input obtained for all the plants in operation at any time during the period December 1941 to August 1945 was 871,040 tons of coal per year.

Karafuto and Korea

Two plants were installed in Karafuto, both using the Lurgi process and with a total rated input of 561,000 tons of coal per year. The plant at Naihoro, the first Lurgi installation in Japan, was designed to be the largest in the Orient; during the period 1940 to 1945 it was the only low-temperature carbonization plant that processed more than 1,000,000 tons of coal. Table 4 gives some details on the plants.

Manchuria

Although one Lurgi carbonization plant was being constructed at Chielin, the installation of carbonizers was only 50 percent complete, and no production was obtained before the end of the war.

Incompleted Plants

Six plants for low-temperature carbonization remained incompleted at the end of the war. The location and approximate size are given in table 5.

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TABLE 3. - Low-temperature carbonization plants in Japan Proper (1923-45)

Name of operating company	Location	Process used	Input capacity, tons coal per year		Operating period		Present status
			Rated	Maximum obtained	Started	Ended	
Nissan Ekitai Nenryo Kogyo K.K.	Wakamatsu, Fukuoka-ken	Lurgi	400,000	219,806	Mar. 1941	Aug. 1945	Operating.
Teikoku Nenryo Kogyo K.K.	Ube, Yamaguchi-ken	Lurgi	400,000	143,091	Nov. 1943	Aug. 1945	Abandoned.
		Koppers	200,000	178,931	Feb. 1942	Aug. 1945	W.B.R.
Ube Kosan K.K.	Ube, Yamaguchi-ken	Koppers	200,000	189,908	May 1934	Aug. 1945	Do.
Osaka Gasu K.K.	Osaka, Osaka-ku	Shimomura	3,000	ND	Sept. 1923	1930	Dismantled.
Toho Kagaku Kogyo K.K.	Nagoya, Aichi-ken	Mimura	100,000	29,971	Oct. 1940	July 1945	Do.
Nihon Yuka Kogyo, K.K.	Kawasaki, Kanagawa-ken	Knowles	70,000	1/22,500	Jan. 1943	July 1945	W.B.R.
Tokyo Gasu K.K.	Tsurumi, Kanagawa-ken	Mimura	100,000	4,311	1940	1943	Dismantled.
Nippon Seitetsu K.K.	Wanishi, Hokkaido	Wanishi	133,000	105,430	1936	Aug. 1945	Operable.

W.B.R.: Will be rebuilt.
1/: Estimated.
ND: No data available.

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TABLE 4. - Low-temperature carbonization plants in Karafuto and Korea

Name of operating company	Location	Process used	Input capacity, tons coal per year		Operating period		Present status
			Rated	Maximum obtained	Started	Ended	
Teikoku Nenryo Kogyo K.K....	Naifuchi, Karafuto	Lurgi	1/330,000	156,733	Dec. 1943	ND	Unknown
Teikoku Nenryo Kogyo K.K....	Naihoro, Karafuto	do.	231,000	261,816	1935	ND	Do.
Chosen Jinzo Sekiyu K.K...	Agochi, Korea	do.	2/200,000	ND	ND	ND	Do.
Nippon Chisso Kogyo K.K....	Eian, Korea	do.	ND	ND	1942	ND	Do.

1/ Existing plant. With completion of new construction, 660,000 tons/year.
2/ Existing plant. With completion of new construction, 350,000 tons/year.
ND: No data available.

TABLE 5. - Incompleted low-temperature carbonization plants

Name of operating company	Location	Process	Expected capacity, tons coal/year	Percent completion of carbonizers	Future status
Nihon Nenryo Kogyo K.K.	Iwamizawa, Hokkaido	1/	ND	0	1/
Nippon Jinzo Sekiyu K.K.	Takikawa, Hokkaido	Knowles (60 ovens)	185,000	10	1/
Do.	Rumoi, Hokkaido	Fiag	200,000	0	None
Hokkaido Tanso Kogyo K.K.	Hiragishi, Hokkaido	Knowles (15 ovens)	93,000	90	1/
Nihon Yuka Kogyo K.K. 2/	Hiragishi, Hokkaido	Knowles (120 ovens)	540,000	0	None
Manshu Jinzo Sekiyu K.K.	Chielin, Manchuria	Lurgi	200,000	50	Unknown

1/ Indefinite. Probably will be completed.
2/ Combined with plant of Hokkaido Tanso Kogyo K.K.
ND: No data available.

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DESCRIPTION OF PLANTS - JAPAN PROPER

Nissan Ekitai Nenryo K.K. - Wakamatsu Works

Location

The plant is in Wakamatsu-shi, Fukuoka-ken, Kyushu. On the northern edge of the Chikuho coal field, it is within a short distance of the largest coal-producing area in Japan. Production from seven nearby mines of coal having the special weakly caking characteristics best-adapted to the process was 1,721,000 tons in 1936, whereas the maximum demand for the plant would be approximately 400,000 tons of coal per year.

History

Founded in February 1939 with a capitalization of ¥10,000,000 shared equally by Nissan Kagaku Kogyo and Teikoku Nenryo Kogyo, this company was formed with the primary objective of producing liquid fuels directly from coal. The method chosen was low-temperature carbonization because of the satisfactorily high yield of liquid products, the simplicity of the process, and the low initial outlay required. The first carbonization unit was placed in operation in March 1941, and immediate plans were made to expand the plant in accordance with the 1941 Government production plan. In December 1941 the capitalization was increased to ¥15,000,000, and at the same time ¥15,000,000 was borrowed from Teikoku Nenryo Kogyo, then 50-percent owned by the Finance Ministry. With these funds, a second carbonizing unit was placed in operation during May 1943, a third in May 1944, and the fourth and last in November 1944. The capitalization of the company was increased to ¥25,000,000 in November 1944, with the entire stock still held by the original two companies.

Equipment

Carbonizer. - The Lurgi system is used at this plant, each of the four carbonizers having a design capacity of 300 tons of coal per day. Original drawings and detailed engineering information were obtained from Lurgi-Gesellschaft, Frankfurt-am-Main, Germany, which also furnished a resident engineer and two erectors to supervise construction of the first unit. With the exception of some special refractory shapes and the burners, which were imported from Germany, this unit was built entirely in Japan. The three carbonizers constructed later were exact copies of the first and were built and operated without outside assistance.

The internal arrangement of the Lurgi carbonizer, including the complicated gas flow patterns, is shown in figure 1. A photograph of the Lurgi carbonizers is shown as figure 2. The method of admitting and withdrawing the gases from each section is evident, as is the means of inducing gas circulation by built-in blowers. Although the equipment appears complex, in reality it is simple in operation, the only moving parts being the rotors of the two circulating blowers, a scraper for preventing accumulations of dust and tar in the offtake gas plenum chamber, the reciprocating grate for removing the semicoke gradually from the carbonizing zone, and the rotary-seal valves for discharging the cooled semicoke onto a belt conveyor.

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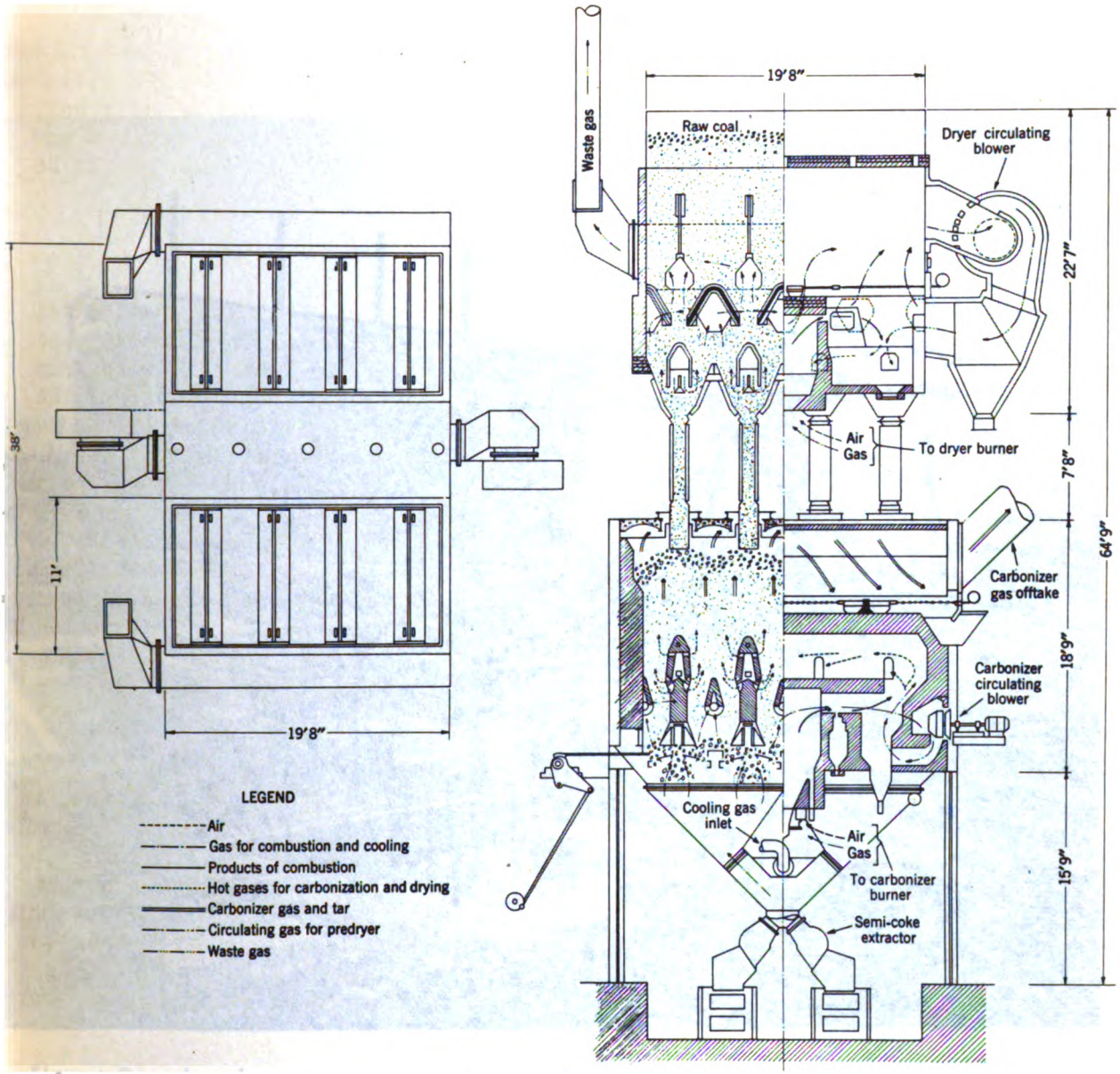

Figure 1. - Lurgi low-temperature carbonizer, showing internal construction and path of gases. Rated capacity, 300 tons of coal per day.

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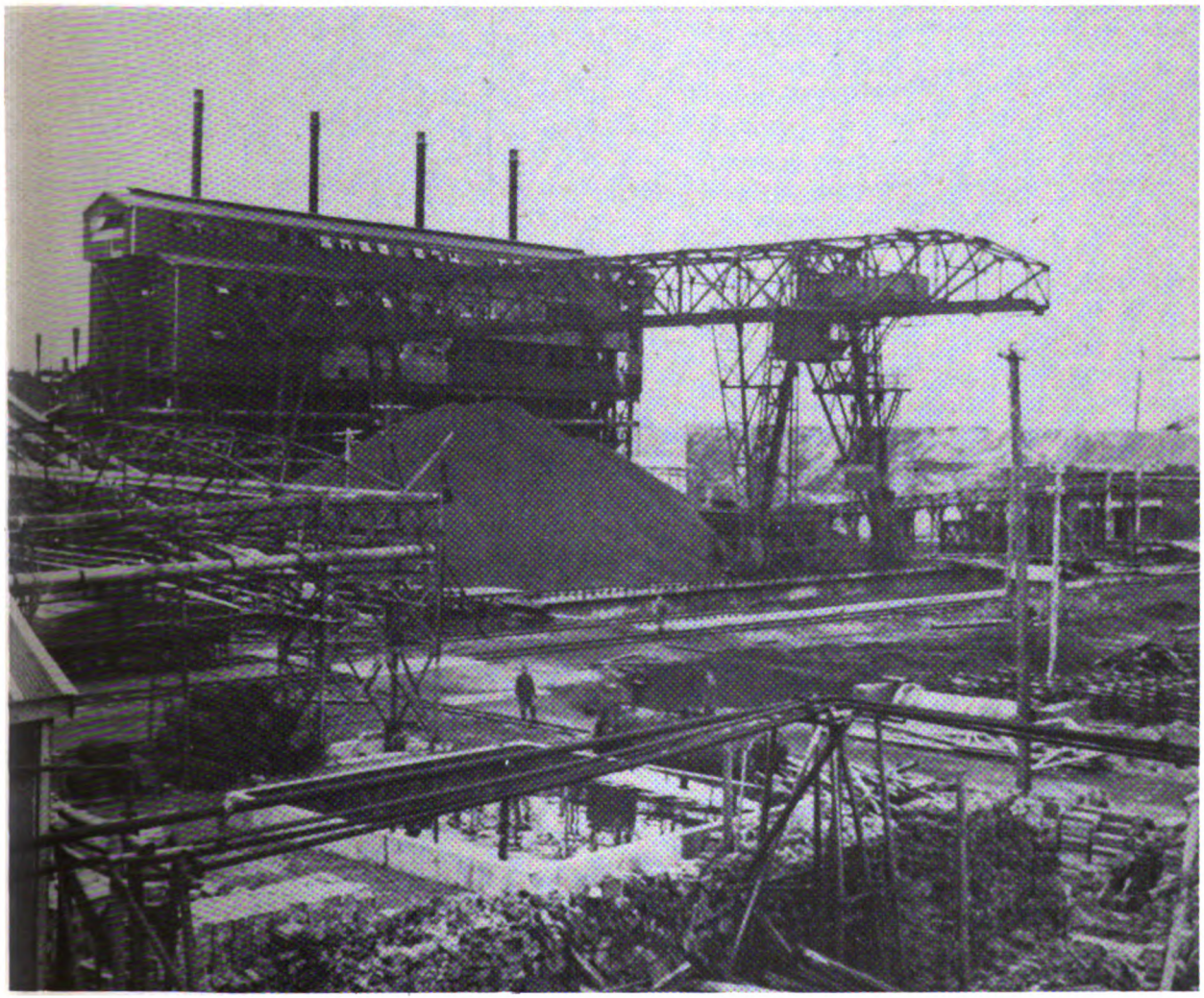

Figure 2. - Lurgi carbonizers at Nissan Ekitai Nenryo Kogyo K. K., Wakamatsu, Fukuoka Prefecture.

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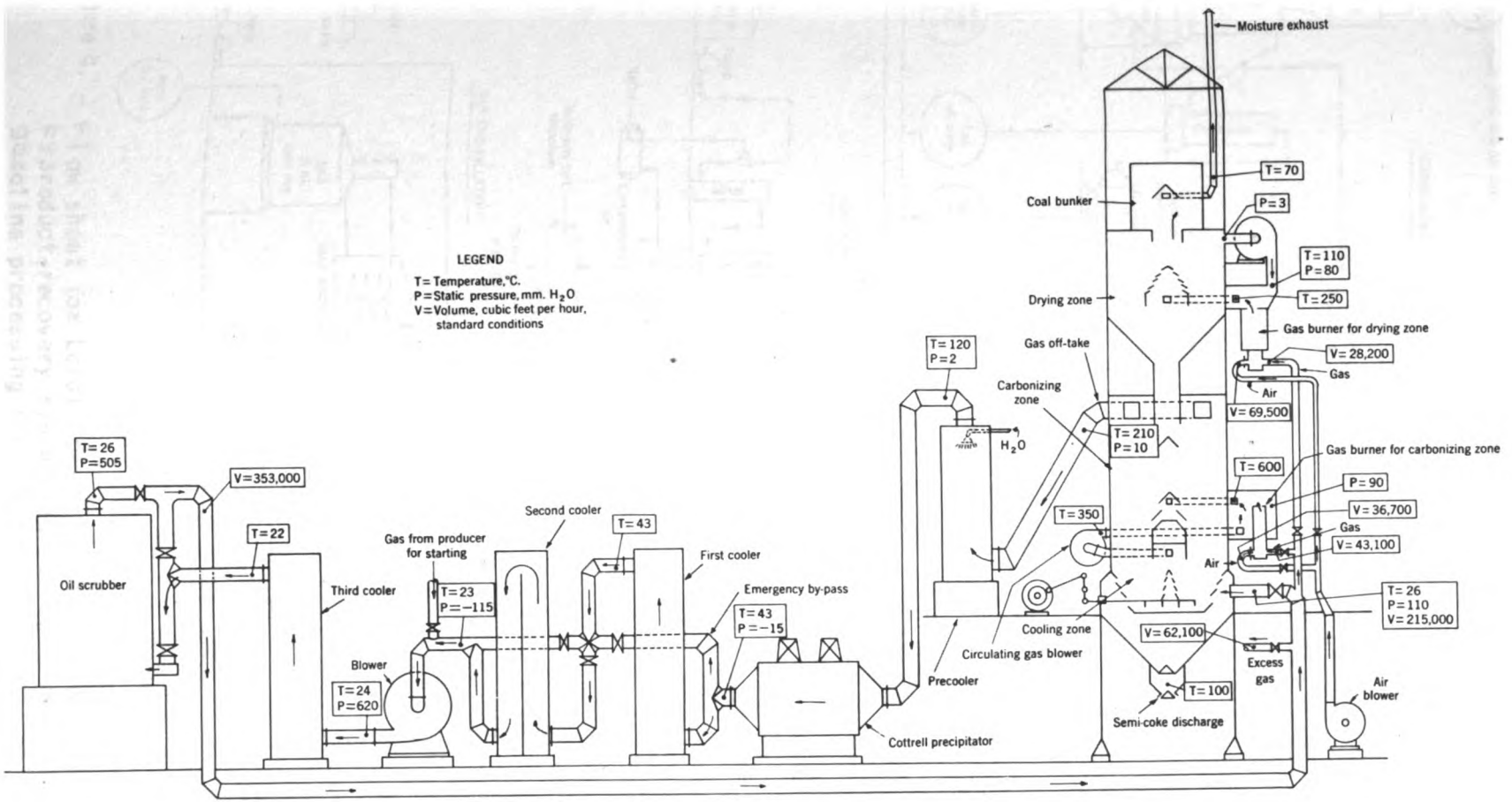

Figure 3. - Lurgi low-temperature carbonizer and byproduct-recovery system, including data on temperature, pressure, and gas flow.

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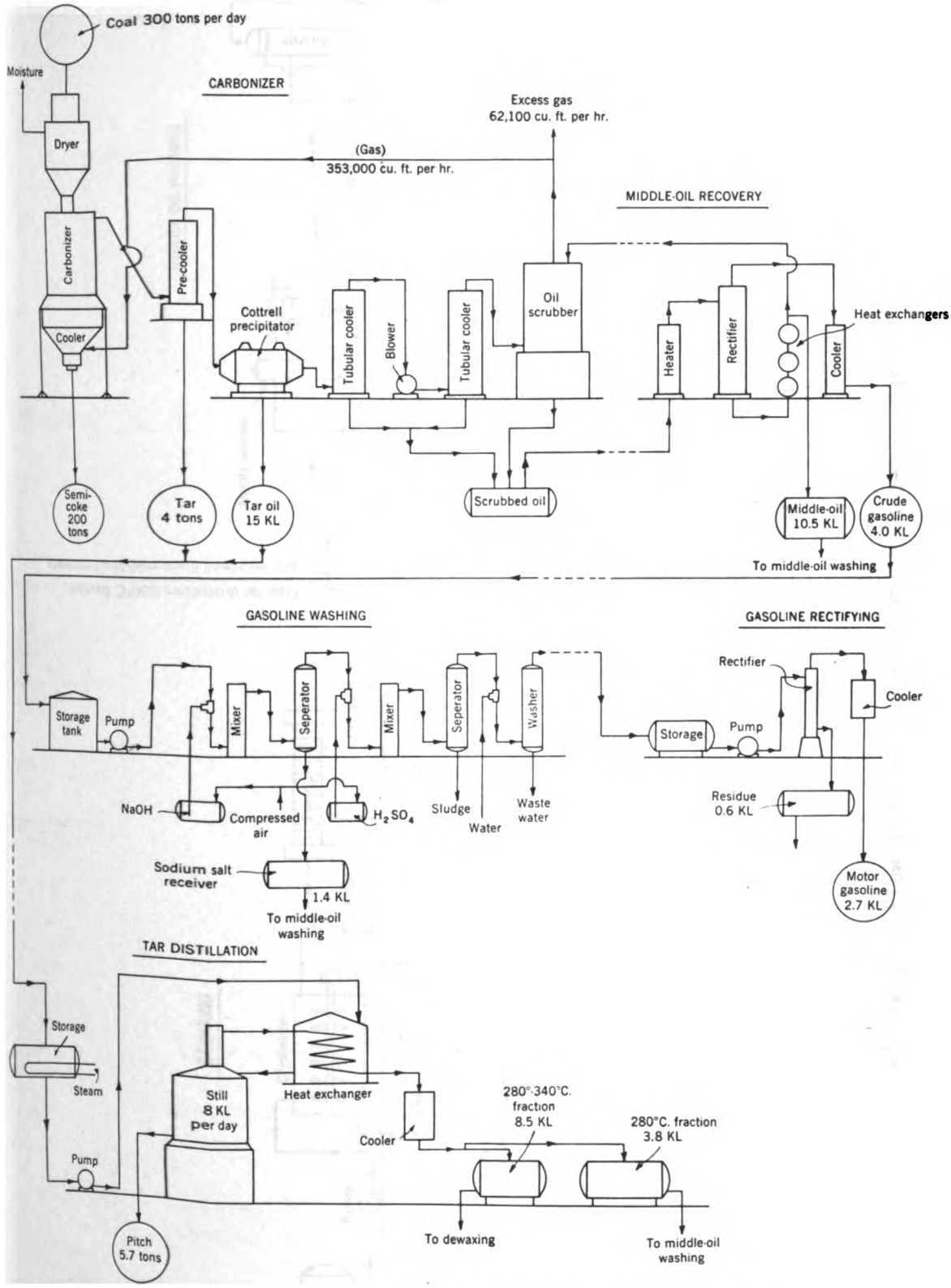

Figure 4. - Flow sheet for Lurgi low-temperature carbonizer and byproduct-recovery system, including middle-oil and gasoline processing and tar distillation.

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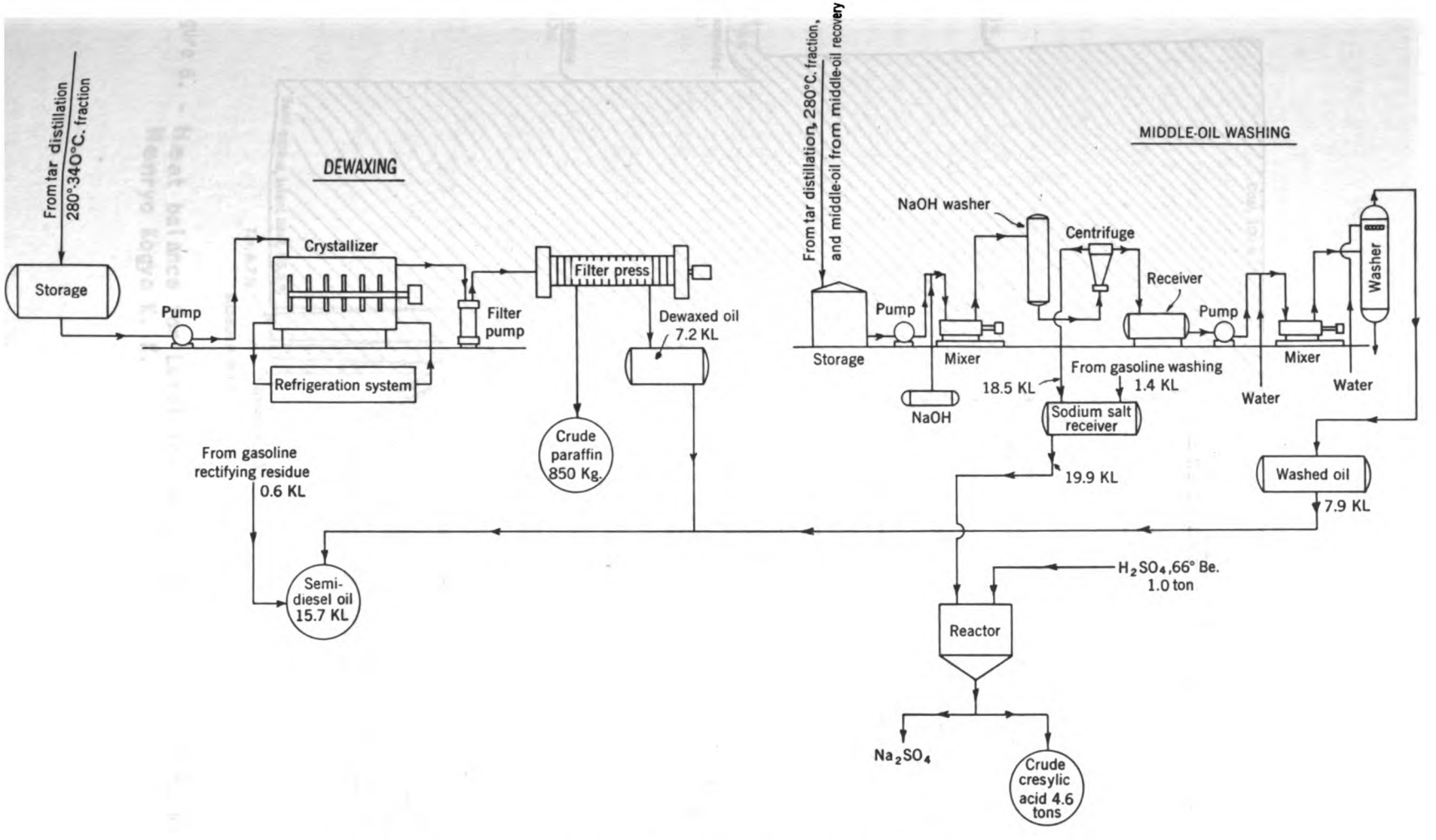

Figure 5. - Flow sheet of dewaxing and middle-oil washing.

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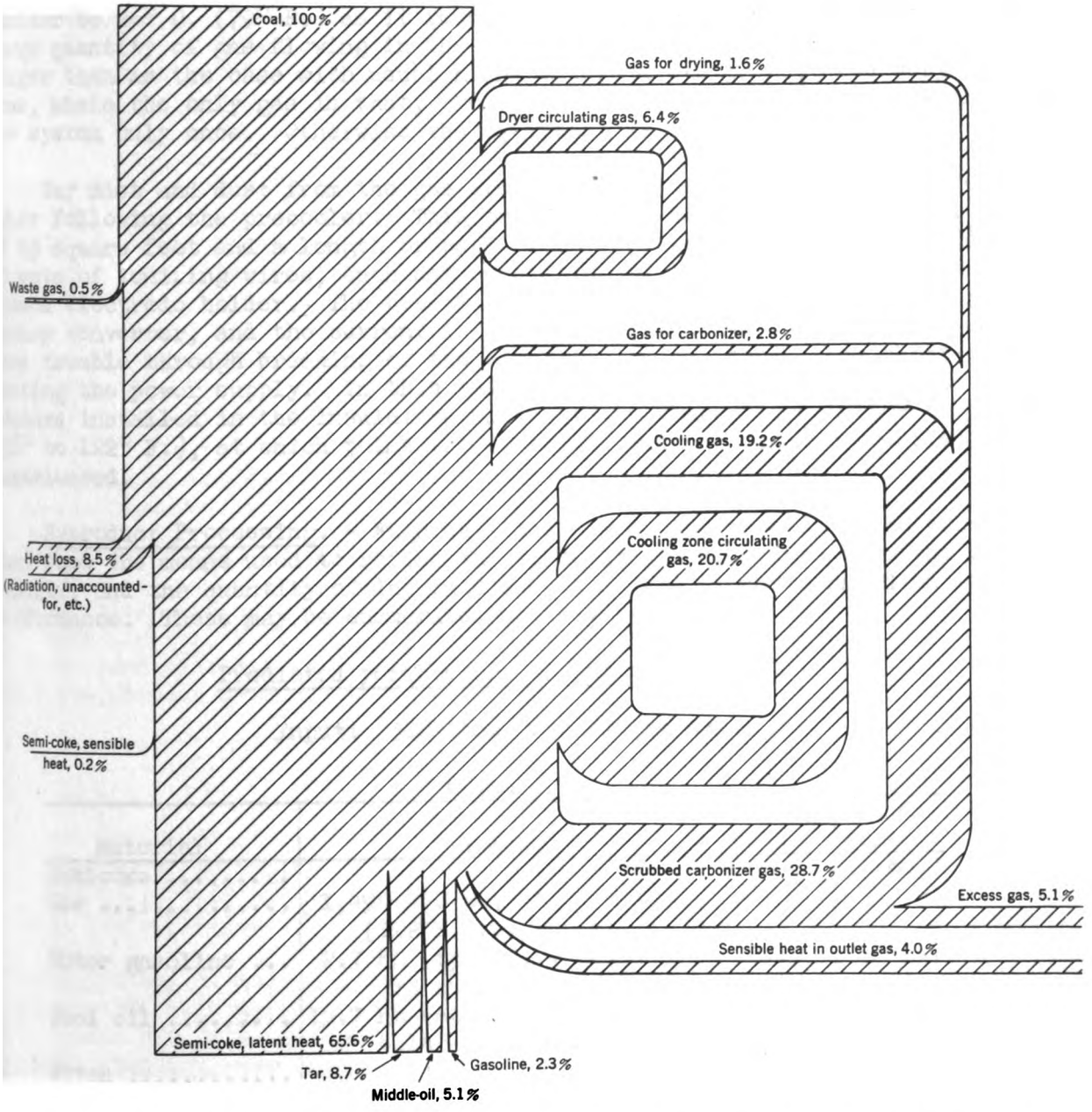

Figure 6. - Heat balance for Lurgi low-temperature carbonizer at Nissan Ekitai Nenryo Kogyo K. K.

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Tar-Recovery System. - The system used for recovering tar is shown schematically in figure 3, in which is included data on the pressure, temperature, and volume of the gas. In all, four cooling towers are used to reduce the temperature of the offtake gas from 210° C. (410° F.) as it leaves the carbonizer to 26° C. (79° F.) as it reenters the cooling zone. Because of the large quantity of gas flowing in the circuit, the size of the equipment is larger than is the case with usual high-temperature byproduct recovery systems, where the only gas is that, evolved from the coal, which passes through the system only once. Otherwise the equipment is not distinctive.

Tar mist and dust from the gas are removed by a single Cottrell precipitator following the precooler. This precipitator has a cross-sectional area of 63 square feet and a length of path of 14 feet. Nine plates are used and 10 sets of ionizing wires, each set consisting of 10 wires hanging from a common electrode holder. The potential used is 50,000 volts supplied by a rotary convertor, and the current is 3 to 4 milliamperes. Such units usually give trouble through bridging of the electrical insulators, thus short-circuiting the power supply. In this case, however, electrical resistance heaters installed in the insulators raises their temperature to 30° to 50° C. (86° to 122° F.), at which point tar does not condense; and no trouble is experienced.

Byproduct Processing. - Figures 4 and 5 are flow sheets of the process. They show the means used to refine the crude liquid materials from the carbonizer, and the quantity of intermediate and final products based on expected performance. These may be summarized as follows:

Predicted performance of Lurgi carbonizer

Input: 300 tons of coal per day.

	Output		
Material	Volume	Weight, tons	Yield, percent
Semicoke	-	200	66.7
Gas	1,490,400 cu. ft. (122 B.t.u./cu. ft.)	-	-
Motor gasoline ...	2.7 KL (sp. gr. = 0.79) 713 gallons	2.13	.7
Fuel oil	15.7 KL (sp. gr. = 0.98) 4,148 gallons	15.4	5.2
Pitch	-	5.7	1.9
Crude paraffin ...	-	.85	.3
Cresylic acid	-	4.6	1.5
Total		228.68	76.3

Heat Balance

A heat balance was computed for a 10-day test during June 1941, when the first unit had been in operation for 3 months. The results are given in the usual graphic form in figure 6; tabulated they are as follows:

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Heat Balance		
Input:	10^6 K-cal.	Percent
Coal	14,500	66.3
Air for combustion (20° C.) (68° F.)	3	0.0
Gas for drying (20° C.)	238	1.1
Gas for carbonization (20° C.)	406	1.9
Cooling gas (20° C.)	2,777	12.7
Dryer circulating gas	925	4.2
Cooling-zone circulating gas	3,005	13.8
Total	21,854	100.0
Output:		
Semicoke, latent heat	9,520	43.6
Semicoke, sensible heat	27	.1
Tar	1,258	5.7
Middle oil	745	3.4
Gasoline	340	1.6
Carbonizer outlet gas, sensible heat (20° C.)	576	2.6
Scrubbed gas	4,168	19.1
Waste gas	70	.4
Dryer circulating gas	925	4.2
Cooling-zone circulating gas	3,005	13.7
Heat loss (by difference)	1,220	5.6
Total	21,854	100.0

Expressed on the basis of the coal charged to the carbonizer, 65.6 percent of the heat input appeared as latent heat in the semicoke; the liquid products contained 16.1 percent and the excess gas 5.1 percent, giving a total thermal efficiency of 86.8 percent. The losses (13.2 percent) were made up of 0.5 percent in the waste gas, 0.2 percent as sensible heat in the semicoke, 8.5 percent through radiation and other unmeasured losses, and 4.0 percent as sensible heat in the gas leaving the carbonizer.

Operating Difficulties

Following the first 13 months of continuous operation, the plant was shut down for inspection, although there had been no evidence that it was not running satisfactorily. The internal condition of the carbonizer was checked carefully, as were the various units in the byproduct-recovery system.

In the carbonizer, severe spalling of the brick lining in the dryer section had occurred, probably because of attack of the mortar by sulfurous and sulfuric acids. Penetration of moisture caused swelling, with the result that the bricks originally 115 mm. (4.53 inches) thick, were reduced to only 65 mm. (2.56 inches). In the lower part of the dryer where the temperatures are higher, no such damage occurred. The steel shell of the dryer section was badly corroded internally, and the cast-iron gas main connecting with the circulating blower also was seriously corroded. The steel duct making up the circulation system was perforated, necessitating replacement. Although the usual design of Lurgi carbonizers includes the removal of sulfur from the gas used for heating in the dryer zone, such provisions were not made in this unit, the application of an acid-resisting paint to the steelwork being used instead. Inadequate protection by the paint film permitted corrosion to occur.

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Deposits of dust and pitch in the carbonization zone resulted in some distortion of gas flow, although insufficient to disturb normal operation. Partial choking of the gas distributors caused tar to condense in the semicoke hopper, while the cooling gas main was almost entirely blocked by a large quantity of coal dust and small-size semicoke. After these deposits were located, a method of regular hand poking using poke holes in the carbonizer and the gas main was developed to prevent such accumulations in future.

Although the blower used for circulating the dryer gases showed no wear, the blading of the cooling-gas blower was badly eroded by dust and was cracked, despite the fact that it was constructed of a heat-resisting alloy steel. There was no unusual wear of the air-gas blower, and the coke extractor was in good condition.

The casing of the precooler was badly corroded, as was the first cooler. All pipes carrying carbonization products were badly attacked, particularly where welded, the same loss of metal being observed in the oil tanks. There was no perceptible damage to the Cottrell precipitator.

Coal Used

Quality. - The coal found most suitable for use in the Lurgi carbonizer was from the Takamatsu mine of Nihon Tanko K.K., located near Orio, Fukuoka-ken. Based on analyses made by the company, the composition of a typical shipment was as follows:

Analyses of Takamatsu coal

Percent					Calorific value,
Proximate analysis					
Moist	Vol. matter	Fixed carbon	Ash	Sulfur	B.t.u./lb.
3.9	38.2	45.3	12.6	0.4	11,860

Ultimate analysis, percent

H_2	C	N_2	O_2	S	Ash
5.5	68.2	1.1	11.8	0.4	13.0

Fisher-Hempel analysis, percent

Tar	Coke	Gas liquor	Gas
12.1	70.6	9.0	8.3

Size consist, percent

Larger than 1 inch	1 inch by 3/8 inch	Smaller than 3/8 inch
65	25	10

This coal is classed as a high-volatile C bituminous coal, according to the A.S.T.M. method of classification by rank. As such, it is similar to many of the coals found in Illinois, Colorado, and Utah and in other midwestern coal fields of the United States.

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The caking tendency of the coal is slight, being only 1.5 to 2.0, as measured by the Campredon-Gray method. In this test, 25 grams of a mixture of sand and finely ground coal is heated to 1,000° C. (1,832° F.) in a platinum crucible, the coherence of the cooled mass being tested by determining its ability to resist crushing. The greatest ratio of sand to coal in a mixture which will just support a 500-gram weight is expressed as the caking index. Strongly caking coals, such as Yubari, have a caking index of 30 by this method; for the noncaking coals from Ube, it is 0.

Effect on Performance. - The output of the carbonizer depends upon the caking power of the coal used, since this property affects the pressure drop through the carbonization zone and consequently the mass flow of hot gases. Strongly caking coals cannot be used because of the formation of lumps of coke, interfering with the flow of the charge by gravity through the carbonizer and upsetting uniform gas-flow conditions. Neither can noncaking coals be used with complete satisfaction because of size degradation, the excessive fines blocking the flow of the carbonizing gases. For instance, tests made with coal from the Ube field having a caking index of 0 showed that the pressure drop through the carbonizer was 80 mm. (3.15 inches water gage, and the maximum input obtainable was 250 tons of coal per day. With Takamatsu coal having a caking index of 1.5 to 2.0, the pressure drop was 40 to 50 mm. (1.57 to 1.97 inches) water gage, and an input of 350 tons per day could be maintained. Using coal of the size consist given above, only 20 percent of the semicoke would pass a 3/8-inch sieve when carbonizing Takamatsu coal, but this was increased to 60 percent with Ube coal. Further the semicoke from Ube coal was extremely friable and had to be handled carefully to prevent further size degradation. Coal from the Fushina field in North China having a caking index of 1.5 gave results similar to that with the Takamatsu coal.

Blending of coal was tried in the attempt to obtain greater production using a minimum amount of Takamatsu coal, since this coal was in great demand by other industries, particularly for use in gas producers. One test showed that a mixture of 80 percent Takamatsu coal and 20 percent coal from the Akaike field with a caking index of 4.5 could be carbonized at a maximum rate of 250 tons per day. Hand poking was required, and occasionally raw coal appeared in the semicoke, although the pressure drop was no higher than with Takamatsu coal alone. Agglomeration sometimes also was noted, for masses consisting of two or three particles of Akaike coal often appeared in the product. If shortages continue in the availability of coals having a caking index of 1.5 to 2.0, future plans of the company include briquetting of the smaller sizes of coal before carbonization, despite the increased costs of this procedure.

Quantity. - The amount of coal carbonized by this plant is listed in table 6. For the period from March 1941, when the plant was put into operation, until August 1945, when it was stopped, 626,240 tons of coal had been carbonized. The greatest input for any one month with only one carbonizer operating was 11,109 tons in April 1943, while in December 1944, just after the fourth unit was placed in service, the maximum monthly input by the plant was reached - 22,010 tons of coal. Since it was usual as a matter of

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policy to keep one carbonizer idle as a spare, this represents the coal used by three units, or a monthly input of 7,337 tons each. An examination of the production data suggests that 8,000 tons of coal per month is the probable average capacity of each unit operated under normal conditions. As the rated capacity is 9,000 tons per month, this represents an expected availability approximately of 90 percent.

Products

Semicoke. - The properties of the semicoke produced are as follows:

Properties of Semicoke

Percent					Calorific value,
Proximate analysis					
Moist	Vol. matter	Fixed carbon	Ash	Sulfur	B.t.u./lb.
1.0	9.5	67.0	22.5	0.4	10,800

Size consist, percent		
Larger than 1 inch	1 inch by 3/8-inch	Smaller than 3/8 inch
40	40	20

Strength

	Material retained on sieve, percent			
	1 inch	5/8 inch	3/8 inch	1/4 inch
Original sample[1]	35.0	100	-	-
Shatter test[2]	22.8	87.0	95.3	96.2
Drum test[3]	6.1	58.4	78.2	83.2

1/ Sample specially selected for size.
2/ 22-pound sample dropped 4 times from height of 6-1/2 feet.
3/ Rotated in closed drum at 15 r.p.m. for 2 minutes.

The high ash content of the semicoke compared with that of the coal suggests that the samples are not directly comparable, although this analysis is considered representative of the semicoke produced at this plant. The strength of the semicoke, although much less than that of high-temperature coke, is considered adequate.

Listed in detail for annual production in table 6, the production of semicoke reached a maximum in December 1944 with 15,550 tons for the month. From the beginning of operation of the plant until it stopped in August 1945, a total of 396,529 tons of semicoke was produced, a yield of 63.3 percent of the coal charged.

The principal use of the semicoke from this plant has been as fuel for portable gas producers on automotive vehicles, where its high reactivity and moderately high bulk density make it a fair substitute for charcoal. Its ash content of 22.5 percent, however, necessitates frequent removal of clinker, although this factor by itself has not been grounds in Japan for rejecting fuel for this application.

Liquid Products. - The properties of the various crude liquid products are given in table 7 and those of the refined products in table 8.

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TABLE 6. - Products from low-temperature carbonization of coal (Japan Proper)

Company and location	Process	Year[1]	Coal charged, tons[2]	Products									
				Semicoke, tons	Motor gasoline		Gas oil		Semi-Diesel oil		Bunker fuel oil		Liquid fuels, total	
					KL	Thousands of gal.	KL	Thousands of gal.	KL	Thousands of gal.	KL	Thousands of gal.	KL	Thousands of gal.
Nissan Ekitai Nenryo Kogyo K.K., Wakamatsu, Fukuoka-ken, Kyushu	Lurgi	1941	81,255	51,297	1,268	335	0	0	0	0	8,053	2,127	9,321	2,462
		1942	78,390	56,373	1,373	363	0	0	0	0	8,308	2,195	9,681	2,558
		1943	175,320	109,174	1,957	517	0	0	1,025	271	14,134	3,734	17,116	4,522
		1944	219,806	139,500	2,365	625	0	0	2,119	560	17,386	4,593	21,870	5,778
		1945	71,469	40,186	519	137	0	0	1,558	412	3,796	1,003	5,873	1,552
		Total	626,240	396,529	7,482	1,977	0	0	4,702	1,243	51,677	13,652	63,861	16,872
Teikoku Nenryo Kogyo K.K., Ube, Yamaguchi-ken, Honshu	Lurgi	1942	ND	ND	796	210	103	27	8	2	9,505	2,511	10,402	2,750
		1943	ND	ND	1,715	453	3,244	857	0	0	14,290	3,775	19,249	5,085
		1944	143,091	ND	2,834	749	1,441	381	207	55	13,910	3,675	18,392	4,860
		1945	39,446	ND	543	143	132	35	1,245	329	2,919	771	4,839	1,278
		Total	182,537	ND	5,888	1,555	4,920	1,300	1,460	386	40,624	10,732	52,882	13,973
	Koppers	1944	178,931	ND	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/
		1945	39,969	ND	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/
		Total	218,900	ND	3/	3/	3/	3/	3/	3/	3/	3/	3/	3/
Ube Kosan K.K., Ube, Yamaguchi-ken, Honshu	Koppers	1938	ND	ND	0	0	0	0	2,175	575	6,719	1,775	8,894	2,350
		1939	ND	ND	1,461	386	0	0	3,457	913	5,009	1,323	9,927	2,622
		1940	185,862	112,422	1,630	431	0	0	2,414	638	5,473	1,446	9,517	2,515
		1941	189,908	116,669	1,450	383	599	158	3,410	901	5,362	1,417	10,821	2,859
		1942	185,759	104,322	1,240	328	953	252	3,369	890	6,399	1,690	11,961	3,160
		1943	167,165	97,123	1,129	298	1,066	282	4,563	1,205	2,738	723	9,496	2,508
		1944	156,764	94,778	1,174	310	1,305	345	4,032	1,065	4,313	1,139	10,824	2,859
		1945	74,485	43,368	142	38	209	55	808	213	1,648	435	2,807	741
		Total	959,943	568,692	8,226	2,174	4,132	1,092	24,228	6,400	37,661	9,948	74,247	19,614
Toho Kagaku Kogyo K.K., Nagoya, Aichi-ken, Honshu	Mimura	1940	6,759	4,374	0	0	0	0	0	0	0	0	0	0
		1941	24,903	16,291	4	1	0	0	0	0	118	31	122	32
		1942	29,971	19,652	0	0	201	53	0	0	943	249	1,144	302
		1943	25,874	17,742	0	0	411	109	0	0	1,088	287	1,499	396
		1944	19,330	13,739	0	0	199	53	0	0	352	93	551	146
		1945	182	127	0	0	0	0	0	0	0	0	0	0
		Total	107,019	71,925	4	1	811	215	0	0	2,501	660	3,316	876
Tokyo Gasu K.K., Tsurumi, Kanagawa-ken, Honshu	Mimura	1941	4,311	2,866	ND	ND	ND	ND	ND	ND	ND	ND	4/ 388	103
		1942	1,677	1,110	ND	ND	ND	ND	ND	ND	ND	ND	4/ 151	40
		1943	200	132	ND	ND	ND	ND	ND	ND	ND	ND	4/ 18	5
		Total	6,188	4,108	ND	ND	ND	ND	ND	ND	ND	ND	4/ 557	148
Nippon Seitetsu K.K., Hokkaido	Wanishi	1936	52,512	39,354	ND	ND	ND	ND	ND	ND	ND	ND	4/ 3,084	815
		1937	80,005	59,948	ND	ND	ND	ND	ND	ND	ND	ND	4/ 5,565	1,470
		1938	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		1939	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		1940	73,780	54,639	ND	ND	ND	ND	ND	ND	ND	ND	4/ 4,814	1,272
		1941	80,710	60,533	ND	ND	ND	ND	ND	ND	ND	ND	4/ 5,447	1,439
		1942	75,630	56,723	ND	ND	ND	ND	ND	ND	ND	ND	4/ 4,965	1,312
		1943	105,430	79,073	ND	ND	ND	ND	ND	ND	ND	ND	4/ 6,052	1,599
		1944	83,495	62,886	ND	ND	ND	ND	ND	ND	ND	ND	4/ 4,854	1,282
		1945	14,955	11,216	ND	ND	ND	ND	ND	ND	ND	ND	4/ 895	236
		Total	566,517	424,372	ND	ND	ND	ND	ND	ND	ND	ND	4/35,676	9,425

1/ Fiscal year, Apr. 1-Mar. 31. 2/ Ton, metric = 2,205 lb. 3/ Included above. 4/ Coal-tar only, not refined. ND: No data available.
Source: Individual companies and Teikoku Nenryo Kogyo K.K.

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TABLE 7. - Properties of crude liquid products, Nissan Ekitai Nenryo Kogyo K.K.

Material	Specific gravity, 15° C.	Proximate analysis: Vol. matter	Proximate analysis: Fixed carbon	Proximate analysis: Ash	Sulfur	Boiling range, °C. percent by volume: 0-170	170-235	235-270	270-350	Residue	Distillate, percent by volume: Acids	Bases	Neutral oils	Softening point, °C.
Precooler tar....	1/1.016	74.5	24.7	0.8	0.26	0	0	1.0	19.5	79.5	ND	ND	ND	46
Cottrell tar oil.	1/ .997	89.6	10.3	.1	.24	0	1.0	6.4	47.0	45.6	ND	ND	ND	32
Crude light oil..	.980	ND	ND	ND	.25	0	20.0	44.6	30.2	5.2	42.0	1.5	56.5	ND
Crude gasoline...	.830	ND	ND	ND	.30	48.6	46.5	5.0	0	0	13.0	2.5	84.5	ND

1/ At 50° C. ND: No data available. Source: Company records.

TABLE 8. - Properties of refined products, Nissan Ekitai Nenryo Kogyo K.K.

Material	Specific gravity, 15° C.	Proximate analysis, percent: Vol. matter	Proximate analysis, percent: Fixed carbon	Proximate analysis, percent: Ash	Sulfur, percent	Residual carbon, percent	Boiling range, °C., percent by volume: 0-170	170-235	235-270	270-350	Residue	Distillate, percent by volume: Acids	Bases	Neutral oil, percent by volume: Neutral oils	Unsaturated	Aromatics	Saturated
Pitch1/	ND	54.9	44.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cresols	ND	ND	ND	ND	ND	ND	1.8	33.7	55.5	9.0	0	ND	ND	ND	ND	ND	ND
Bunker fuel oil2/	3/0.967	ND	ND	ND	ND	2.55	.5	3.7	9.8	26.6	59.4	36.5	0.5	63.0	ND	ND	ND
Semi-Diesel oil4/	3/ .941	ND	ND	ND	0.3	.45	.9	10.3	28.8	40.0	20.0	19.0	2.0	79.0	ND	ND	ND
Motor gasoline...	.795	ND	ND	ND	ND	ND	72.6	27.4	0	0	0	.0	.5	99.5	10	34	56

ND: No data available.
1/ Melting point = 150° C.
2/ Melting point = 31° C. Flash point = 118° C. Viscosity, Redwood seconds at 50° C. = 174.
3/ At 50° C.
4/ Melting point = 13° C. Flash point = 87° C. Viscosity, Redwood seconds at 50° C. = 36.

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Although the data on physical properties and chemical compositions are incomplete in many respects, enough are available in general to describe the products satisfactorily. The bunker fuel oil is approximately equivalent to No. 5 fuel oil in viscosity but contains excessive carbon residue. The semi-Diesel oil performs satisfactorily in the engines of fishing boats, in which it is largely used, and the gasoline is suitable for modern automobile engines. According to the information furnished, none of the liquid fuels produced in this plant were used for military purposes, the entire output being distributed to civilian consumers.

The greatest production of liquid products was in 1944, when 21,870 KL (5.8 million gallons) was refined. Total production of the plant until August 1945 was 63,861 KL (16.9 million gallons); the individual products were as follows:

Basis	Bunker fuel oil	Semi-Diesel oil	Motor gasoline	Total
Kiloliters	51,677	4,702	7,482	63,861
Gallons, thousands	13,652	1,242	1,977	16,871
Tons	49,971	4,424	5,948	60,343
Percent by weight	82.8	7.3	9.9	100.0
Yield, percent of coal charged	7.98	.71	.95	9.64

Prior to installing the equipment, a yield of 90 percent of the Fisher-Hempel assay was guaranteed by Lurgi Gesellschaft. Based on the analysis of the Takamatsu coal, which gave 12.1 percent tar, this would amount to a 10.9 percent tar yield. The actual yield of refined liquid products of 9.64 percent is considered satisfactory by the operators.

Gas. - The composition of the gas leaving the carbonizer was:

Percent							Cal. value,
CO_2	O_2	H_2	CO	CH_4	CnHm	N_2	B.t.u./cu. ft.
9.2	0.3	10.3	6.6	12.7	0.7	60.2	200

The relatively high values of CO_2 and N_2 result, of course, from the presence of products of combustion entering from the burner and supplying the heat for the carbonizer. These products of combustion had the following composition, as measured at the burner outlet:

Percent			
CO_2	O_2	CO	N_2
8.8	0.4	5.6	85.2

No data are available on the total quantity of excess gas produced during operation of the carbonizer. Such gas was piped directly to the power plant and burned to generate steam for use within the plant.

Others. - The recovery of coal-tar pitch was not begun until October 1943. From then until August 1945, 874 tons of pitch was produced, the

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maximum annual production being 396 tons. Although this material was sold on the open market, it would be used as a binding agent within the plant if briquetting of fine coal becomes necessary. Since 5 percent binder is commonly used in such applications, the pitch obtained from the process would be sufficient to briquet only about 8,000 tons of coal per year; thus it would be necessary to purchase additional binder.

Cresols were recovered beginning in January 1944; total production until the plant stopped was 388 tons. This material was sold through the Tar Distribution Control Association, the end uses being medicinal, agricultural, and the manufacture of plastics.

Operation of the dewaxing plant was started in November 1943, but only 36 tons of crude paraffin was produced in all. Difficulty in the operation of the filter presses used to reclaim the paraffin was primarily responsible.

Composition. - Because this plant was operating at the time the inspection was made, samples of the coal, semicoke, tars, and middle oil were obtained for analysis. In the case of the coal and semicoke, small increments were withdrawn at short intervals from moving streams of the materials on conveyors, the total sampling time being about 8 hours. No such sampling of the liquid products was possible, and it was necessary to take grab samples from sumps or tanks; because of the high fluidity of these materials at the time, the samples obtained are probably fairly representative. After packing in airtight cans to prevent oxidation or loss of moisture, the samples were sent to the Central Experiment Station of the Bureau of Mines at Pittsburgh, Pa., where they were analyzed under the direction of H. M. Cooper, supervising chemist, Coal Analysis Section, and J. D. Davis, supervising chemist, Coke Section.

The composition of the coal from the Takamatsu mine near Orio, in the Chikuho coal field, Kyushu, and the semicoke produced from it in the Lurgi carbonizer of Nissan Ekitai Nenryo Kogyo K.K. is shown in table 9. With the exception of the ash content, the proximate and ultimate analyses of the coal are about the same as those furnished by the plant. The volatile matter in the semicoke is about one-half of that reported by the plant laboratory, but this property is likely to change widely with moderate variations in operating procedure. At the time of the sampling, when coal shortages were severe, the carbonizer was being operated at a low throughput so that the period during which the coal was in the carbonizer was unusually long. Under such conditions, semicoke of low volatile-matter content is to be expected.

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TABLE 9. - Analysis of coal and semicoke, Nissan Ekitai Nenryo Kogyo K.K.[1]

Material	Percent by weight[2]										Cal. value, B.t.u. per lb.
	Proximate analysis				Ultimate analysis						
	Moist	Vol. matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Ash	
Coal....	4.8	38.0	35.2	22.0	5.1	57.0	1.0	13.9	1.0	22.0	10,310
Semicoke	3.8	5.7	63.6	26.9	1.8	64.7	1.0	5.0	.6	26.9	10,080

Forms of sulfur, percent[2]

	Sulfate	Pyritic	Organic
Coal....	0.012	0.406	0.538
Semicoke	.024	.037	.489

Ash-fusion temperature, °F.

	Initial deformation temp.	Softening temp.	Fluid temp.
Coal	2,680	2,740	2,810
Semicoke.	2,780	2,860	2,890

Size consist, inches, percent[3]

	+2-1/2	-2-1/2, +2	-2, +1-1/2	-1-1/2, +1	-1, +3/4	-3/4, +1/2	-1/2, +3/8	-3/8, +1/4	-1/4
Coal	7.0	15.0	25	29	11.5	7.8	2.7	4/2.0	-
Semicoke.	-	-	1.6	22.4	26	28	11	7.0	4.0

Rosin-Rammler parameters

	Distribution coefficient	Absolute size constant, in.
Coal	2.48	1.72
Semicoke	2.46	.82

Coal:

Real specific gravity	1.463
Grindability, Hardgrove (A.S.T.M. method D-409-37T)	41
Free swelling index	1
Agglutinating value (Bureau of Mines method), with 15:1 ratio of silicon carbide to coal. Crushing strength, kilograms	0.5

1/ Analyzed in the laboratories of the Bureau of Mines, Central Experiment Station, Pittsburgh, Pa.
2/ As-received basis.
3/ Recomputed by use of Rosin-Rammler relationship.
4/ 3/8-inch by 0.

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Of particular interest is the difference in forms of sulfur in the coal and the semicoke. The analyses indicate that 0.4 percent sulfur was transferred from the coal to the volatile products of carbonization and that this sulfur came almost entirely from the pyritic sulfur in the coal. Thus, despite the reducing conditions normally associated with carbonization, it is evident that oxidation of the sulfur forms occurred, with the sulfate sulfur doubled, the pyritic sulfur decreased to less than 10 percent of that in the coal, and the organic sulfur lowered to approximately 90 percent of that in the coal. It would appear, therefore, that this method of carbonization can produce semicoke lower in sulfur content than the original coal, the decrease being almost exactly equivalent to the pyritic sulfur in the coal. Since this effect probably takes place in the drying section of the unit, modifications in the dryer operation would be expected to affect the sulfur content of the semicoke.

Size degradation of the coal during carbonization is shown by the Rosin-Rammler parameters. Because the distribution coefficients of the coal and semicoke are the same, no difference existed in the relative percentage of fines before and after carbonization. The absolute size constant of the semicoke, however, is only one-half that of the coal. These data show, therefore, that carbonization of the Takamatsu coal has produced a semicoke with about the same proportions of large and small pieces as the original coal, but smaller in average size.

The caking tendency of the coal, as indicated by the free-swelling index and the agglutinating value, is very slight; thus this factor also is in agreement with the determination made in Japan by the Campredon-Gray method.

A test of the reactivity of the semicoke according to the C.I.T. ignitibility method showed it to be less reactive than charcoal but much more reactive than high-temperature coke. Actual comparative data follow:

	Reactivity of semicoke and other fuels °C.	
Material	T_{15}	T_{75}
Charcoal	214	238
Semicoke (Japan)	258	344
High-temp. coke	517	567

In this test, reactivity is expressed indirectly as the temperature at which the fuel attains a specified rate of self-heating under closely controlled conditions. Thus, T_{15} is the temperature when the fuel under test liberates enough heat to cause its temperature to increase at the rate of 15° C. per minute in oxygen. Similarly, T_{75} is the temperature where the self-heating rate is 75° C. per minute. Obviously, as T_{15} and T_{75} are lower, the reactivity of the fuel is greater. Further, as the difference between these temperatures decreases, the reactivity would increase.

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The three samples of liquid products were examined according to procedures developed by the Bureau of Mines for testing the carbonizing properties of coals; the analyses are shown in table 10. The precooler tar resembled a pitch, being very viscous and difficult to distill. Most of the distillate evidently was formed by cracking, while the amount of free carbon present was high (5.5 percent). Tar from the Cottrell precipitator resembled usual low-temperature tar in appearance but yielded more residue and less distillate than average low-temperature tars. Also, it contained slightly less acids and bases and considerably less neutral oils. The middle oil, obtained in an intermediate step of processing, had a high acid content, which, with the boiling range, indicates large proportions of phenols, cresols, and xylenols.

Costs

Cost of construction of the plant amounted approximately to ¥5,000,000 for each unit, based on 1942 prices when structural steel cost ¥230 per ton and laborers, such as welders and machine operators, were being paid ¥15 per day. Each such unit was expected to carbonize 100,000 tons of coal per year with a yield of 10,000 tons of liquid fuels and 65,000 tons of semicoke; thus, the investment costs are ¥500 per ton of liquid fuel capacity per year or ¥76 per ton of semicoke capacity per year. In comparison with the cost of producing liquid fuels from synthesis gas, the company estimated that a Fischer-Tropsch plant with a rated capacity of 20,000 tons of fuel per year had cost ¥50,000,000. Since this Fischer-Tropsch plant, built in Japan, actually produced only 10,000 tons of fuel per year as a maximum, its basic construction cost was ¥5,000 per ton of liquid fuel per year, or 10 times the investment for the Lurgi carbonizer. Despite the increased yield of liquid products obtained by the Fischer-Tropsch process per ton of coal and the difference in the ratio of gasoline to fuel oil obtained, the lower investment costs of the Lurgi carbonizer and its greater ease of operation permit it to retain a favorable competitive position as a source of liquid fuels from coal. This position, of course, might change abruptly with expected engineering improvements in the Fischer-Tropsch process.

The unit production cost in 1944, not including profit, was:

Material	Unit production cost
Semicoke	¥ 53
Pitch	50
Cresol	747
Bunker fuel oil	60
Semi-Diesel oil	146
Motor gasoline	337

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TABLE 10. - Analysis of dry liquid products, Nissan Ekitai Nenryo Kogyo K.K.[1]

Material	Specific gravity, 15.6° C. / 15.6° C.	Heating value, B.t.u. per pound	Percent by weight: Ultimate analysis: Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Free carbon	Wax	Naphthalene salts	Boiling range, °C., percent by volume: 0-170	170-235	235-270	270-350	Residue
Precooler tar[2]	1.08	16,500	8.6	83.0	0.9	5.3	0.5	5.50	0	0	2.8	5.1	4.4	13.3	74.4
Cottrell tar	.98	16,420	9.1	83.1	.9	6.4	.5	.64	0.60	0	.8	3.3	6.4	25.1	64.4
Middle oil	.97	16,890	9.8	81.8	.5	7.6	.3	.15	0	0	2.2	43.7	21.5	26.0	6.6

Analysis of tar distillate[1]

Material	Distillate, percent by volume of dry tar: Acids	Bases	Neutral oils	Neutral tar oil percent by volume: Olefins	Aromatics	Paraffins and naphthenes
Precooler tar	5.6	0.8	19.3	14.5	44.4	41.1
Cottrell tar	14.0	1.4	19.7	17.1	49.4	33.5
Middle oil	38.9	2.1	52.3	14.0	47.6	38.4

1/ Analyzed in laboratories of the Bureau of Mines, Central Experiment Station, Pittsburgh, Pa.
2/ Ash, 1.7 percent.

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Estimated cost of production per month in 1946 is:

Material	Estimated monthly production	Unit production cost, including 5 percent profit	Total production cost
Semicoke.....	6,500 tons	¥ 360	¥ 2,340,000
Pitch	100 tons	100	10,000
Cresol	50 KL (13,209 gal.)	6,740	337,000
High phenols ..	60 KL (15,851 gal.)	366	28,600
Bunker fuel oil	200 KL (52,836 gal.)	276	55,200
Semi-Diesel oil	400 KL (105,672 gal.)	475	190,000
Motor gasoline.	100 KL (26,418 gal.)	1,027	102,700
		Total..	¥ 3,063,500

Expenditures would be as follows:

Materials:

Item	Estimated monthly consumption, tons	Unit price	Total cost per month
Coal	10,000	¥ 150	¥ 1,500,000
Caustic soda	50	7,000	350,000
Sulfuric acid	60	200	12,000
			¥ 1,862,000

Labor and operational expenses:

Labor	387,700
Electric power	24,000
Steam	50,000
Water	22,000
Maintenance	153,000
Freight	2,500
Depreciation	155,000
Taxes and insurance	32,500
Housing, hospital, etc.	44,000
Chemical laboratory	8,800
Office expenses, including 5 percent profit	319,000
	¥ 1,201,500
Total expenditures	3,063,500

These data are only relative, because of the rapidly changing value of the Yen.

Present Status

This plant operated without war interference until August 8, 1945, when it was halted by incendiary bombing. Total damage amounted to about ¥1,000,000, consisting principally of destruction of oil- and tar-pumping

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equipment and burning of intermediate oil tanks and the wooden packing and other parts of two of the four water-cooling towers. There was only superficial damage to the carbonizers.

Repair of the oil- and tar-pumping equipment was completed first, and on April 29, 1946, one carbonizer was returned to service. Inability to obtain Takamatsu coal in adequate quantities prevented operation of additional carbonizers, but as coal becomes more available other units will be started, minor damage now being repaired. Since this plant is ready to operate essentially at rated capacity, it is the only potential source of semicoke and low-temperature tar in western Japan.

Teikoku Nenryo Kogyo K.K. - Ube Works

Location

The occurrence of large amounts of noncaking coal in the Ube-Onoda field in western Honshu led to the establishment of this plant at Ube, Yamaguchi-ken. The 14 major mines in this area produced 2,811,000 tons of coal in 1943 and 3,115,000 tons in 1944. Although the coal is of low rank and not ideally suited for low-temperature carbonization, it is similar in type to that used in Germany for this purpose.

History

Originally incorporated in August 1939 as the Ube Yuka Kogyo K.K. with a capital of ¥50,000,000, invested jointly by Teikoku Nenryo Kogyo K.K. and Ube Kosan K.K., the plant was taken over completely in October 1944 by Teikoku Nenryo Kogyo K.K. and operated by them until the end of the war. Original plans called for the annual production of 40,000 KL (10.6 million gallons) of gasoline and 150,000 tons of synthetic ammonia, using both Koppers continuous vertical ovens and Lurgi low-temperature carbonizers as a source of semicoke, synthesis gas, and tar. Later, production plans were expanded to produce 90,000 KL (23.8 million gallons) per year of low-temperature tar by increasing the number of Lurgi carbonizers to 10. Construction of the works began in October 1939, and the first Koppers ovens were placed in operation in February 1942. The Lurgi carbonizers began operating successively in November 1943, April 1944, December 1944, and April 1945, the fifth unit being 55 percent complete at the end of the war. In February 1943 a plant was begun to produce lubricating oil from rubber, and in the same year construction was started on a synthetic methanol plant.

Equipment

Lurgi Carbonizer. - The Lurgi carbonizers used at this plant are an exact duplicate of those constructed by Nissan Ekitai Nenryo K.K. at Wakamatsu. No assistance of foreign engineers was required in construction or early operation, the interlocking ownership permitting the experience gained at Wakamatsu to be utilized fully. In addition, the availability of the Wakamatsu plant for training personnel made initial operating problems negligible.

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Also exactly similar are the tar-recovery and byproduct-processing systems, which were built according to the same plans as those used at Wakamatsu. Minor differences in operating procedure caused the pressure of the products of carbonization circulating in the recovery system to be somewhat different. These pressures are tabulated below:

Static pressure of gas in external circulating system, Lurgi carbonizer

Position	Pressure, water gage	
	Mm.	In.
Carbonizer gas offtake	+ 10	+ 0.39
Entering Cottrell precipitator	- 30	- 1.18
Entering first cooler	- 50	- 1.97
Entering main gas blower	-100	- 3.94
Leaving main gas blower	+800	+31.50
Entering oil scrubber	+700	+27.62
Leaving oil scrubber	+450	+17.70
Leaving carbonizing circulating blower	+ 70	+ 2.75
Entering dryer circulating blower	- 20	- .79
Leaving dryer circulating blower	+100	+ 3.94

The predicted performance of the carbonizer was as follows:

Input: 300 tons of coal per day.
Output:

Material	Volume	Weight, tons	Yield, percent
Semicoke	-	195	65.0
Gas	1,270,000 cu. ft. (198 B.t.u./cu.ft.)	-	-
Crude gasoline	3.0 KL (Sp. gr. = 0.78) 793 gallons	2.3	.8
Low-temperature tar	25.5 KL (Sp. gr. = 0.98) 6,737 gallons	25.0	8.3
		222.3	74.1

Based on the latent heat in the coal charged, a rough heat balance was made during the early months of operation of the plant.

Heat balance

Basis: 1 lb. of coal, 9,360 B.t.u.

Product	B.t.u.	Percent
Semicoke	5,580	59.6
Crude tar	1,480	15.8
Crude gasoline	189	2.0
Excess gas	382	4.1
Losses (by diff.)	1,729	18.5
Total	9,360	100.0

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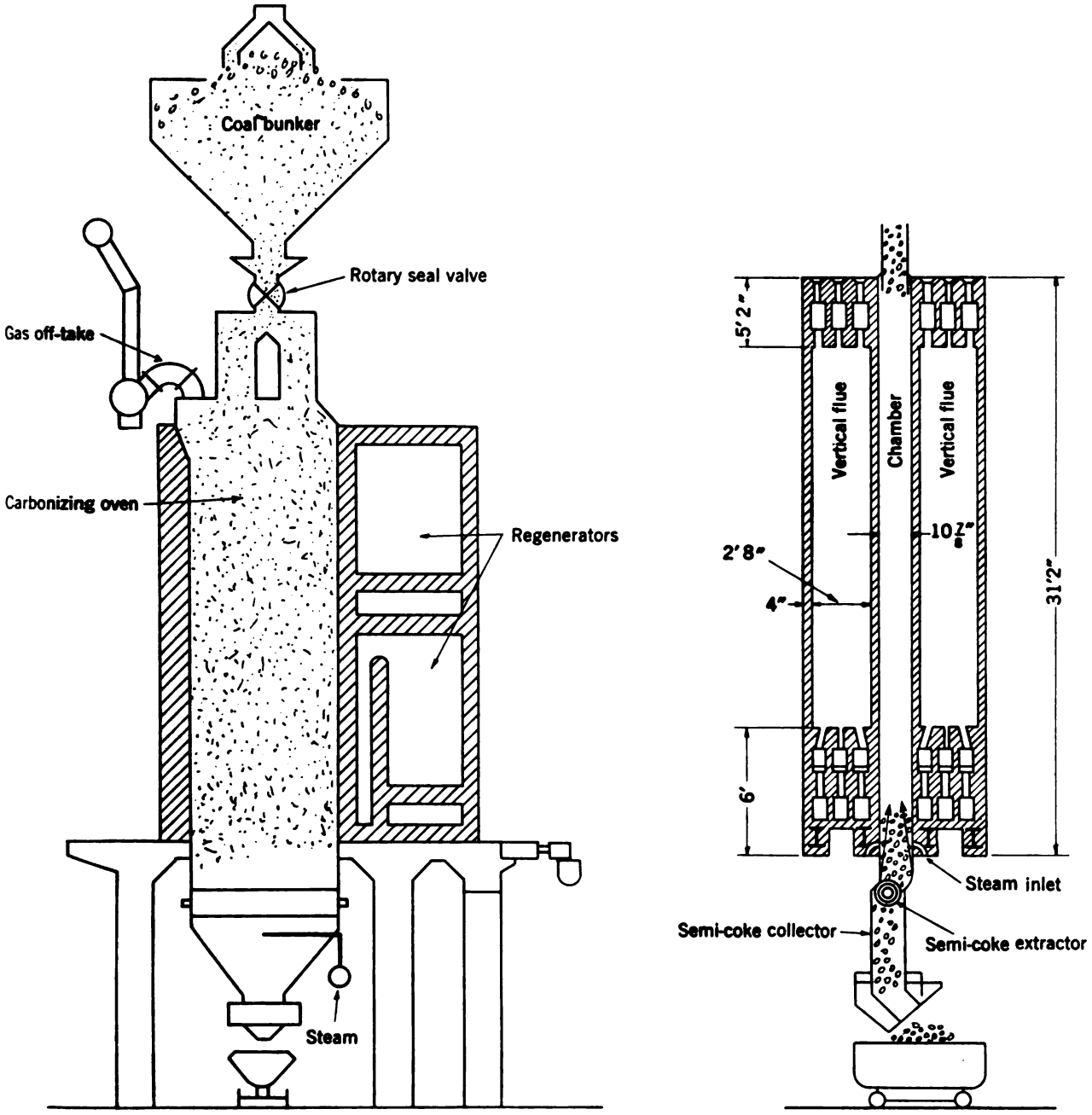

Figure 7. - Koppers continuous vertical steaming coke oven.

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The thermal efficiency of 81.5 percent is 5.3 percent lower than at Nissan Enitai Nenryo. Most of the decreased efficiency occurs because of the lower thermal yield of semicoke, probably because of the higher inherent moisture content of the Ube coal.

Difficulties in operation were caused principally by the friable nature of the coal and its lack of caking power, resulting in the production of excessive fines. This caused the pressure drop across the carbonizing zone to be too large, interfering with normal gas distribution. Also, the semicoke tended to crush when passing through the oscillating grate, so that the suction line on the carbonizing circulating gas blower became clogged. At an input of 300 tons of coal per day the blower required cleaning at monthly intervals, necessitating shutting down the entire unit. Trouble was also caused by the dust in the precooler, where it gradually accumulated, and in the Cottrell precipitator, where it bridged across the insulators. At 250 tons of coal per day, operation could be maintained for 2 months before general cleaning became necessary; at 200 tons per day, 6 months uninterrupted operation was considered feasible. The longest actual continuous operating period for a carbonizer using Ube coal was 4 months.

Koppers Continuous Vertical Coke Ovens. - These ovens are arranged in 2 banks, each consisting of 36 chambers divided into 6 batteries of 6 chambers each. Each battery is 26 feet long and is separated from the adjoining battery by a narrow, air-cooled chamber. The over-all width of a bank is 25 feet, including the regenerators, and the height of the carbonizing zone is 31 feet. The carbonizing chambers are 12 feet 9 inches long and taper in width from 10-5/8 inches at the top to 11-3/4 inches at the bottom to facilitate the movement of the charge; the volume of each chamber is approximately 350 cubic feet. Rated capacity of the 72 chambers is 600 tons of coal per day, the coal requiring 21 hours to pass through the unit. Regenerators are conventional in design and operate on a 30-minute cycle. When rich coke-oven gas is burned, it is admitted after the air has been preheated; with less producer gas, the air and gas pass through separate flues of the regenerators. The general arrangement of regenerators and oven is shown in figure 7.

An important modification in these ovens is the addition of steam at 300° C. (572° F.) to the bottom of the carbonizing zone. Amounting to 60 percent by weight of the coal charged, this steam is about 40 percent dissociated; thus 144 tons of steam per day is converted into water gas at the expense of about 175 tons of semicoke containing an estimated 55 percent carbon. The addition of this large quantity of steam increases the rate of heat transfer from the hot refractory walls to the charge of coal, increases the quantity of gas formed, and decreases the carbonization temperature to 700°-850°C. (1,292-1,562° F.) although the temperature of the flues may be as high as 1,000° C. (1,832° F.). The heat required for carbonization and to carry on the water-gas reaction is 800 to 1,200 B.t.u. per pound of coal.

The tar-recovery and byproduct-processing systems are conventional, being similar to those used in standard coke-oven practice. Dust in the offtake gas is not particularly troublesome and is removed along with the tar by passing

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the gas through the usual coolers and centrifugal tar separators; no electrical precipitators are used. The usual dry box is employed for removing sulfur, and although a Thylox plant was planned for recovering sulfur from the gas, it was not completed and never placed in operation.

The principal difficulties involved in operating this plant were incurred through the formation of clinker in the lower sections of the ovens, cracks in the wall permitting leakage of air and combustion of part of the semicoke. Gradually accumulating on the face of the refractory, thus interfering with heat transfer and allowing its temperature to increase to 900°-1,000° C. (1,652°-1,832° F.) masses of clinker eventually became so thick that daily poking was required to maintain a continuous flow of semicoke. The composition of the coal ash was:

Coal-ash analysis, percent

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Alk.
51.6	22.1	5.7	8.7	1.8	6.3	3.8

and its cone-fusion softening temperature was 1,100° C. (2,012° F). Other difficulties included clogging of the regenerators with dust from dirty producer gas, making cleaning at 3-year intervals necessary. The presence of 6.6 grains of sulfur per cubic foot of gas caused severe corrosion of gas-offtake and main gas lines.

Coal Used

Quality. - The same coal is used in both the Lurgi carbonizers and Koppers ovens and is obtained from the Okinoyama colliery in the Ube-Onoda field Yamaguchi-ken. In 1944 this mine produced 1,046,000 tons of coal. The analyses of typical samples of coal follows:

Analyses of Okinoyama coal

Proximate analysis, percent				Calorific value,
Moist	Vol. matter	Fixed carbon	Ash	B.t.u./lb.
8.6	38.0	32.8	20.6	9,540

Ultimate analysis, percent1/							Calorific value,
Moist	H_2	C	N_2	O_2	S	Ash	B.t.u./lb.
10.4	4.4	56.3	0.8	12.8	0.8	14.5	10,100

1/ Not same sample as used for proximate analysis.

Size consist, percent

Larger than 1 inch	1 inch by 3/8 inch	Smaller than 3/8 inch
65	25	10

Although classed as a "lignite" by the operators, this coal is more properly considered a subbituminous A coal, according to the A.S.T.M.

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classification of coals by rank; it is both weathering and nonagglomerating. This coal has no tendency to become plastic when heated, the caking index by the Campredon-Gray method being zero.

Quantity. - Production and consumption data for this plant are available only since April 1944 and are given in summarized form in table 6. The Lurgi carbonizers operated at maximum total rating in December 1944, when 17,647 tons of coal was carbonized. Because the third carbonizer had just been placed in service, this represents a daily input of 190 tons for each unit per day, or 63 percent of rated capacity. During May 1944, two units carbonized 15,128 tons of coal, or 244 tons each per day - 81 percent of rated capacity. Degradation of the coal, with production of excessive fines, is responsible for the decrease in capacity below the daily rated input of 300 tons.

Maximum input to the Koppers ovens was in May 1944, when 18,113 tons of coal was carbonized, or 585 tons per day. For the 15 months following April 1944, 218,900 tons of coal was carbonized, a daily rate of 480 tons. Compared with the rated input of 600 tons of coal per day, these data indicate that approximately rated capacity can be maintained for short periods, but that continuous operation is possible only at a much lower level.

Products

Semicoke. - Semicoke produced by the Lurgi carbonizers had the following analysis:

Analysis of Lurgi semicoke

Proximate analysis, percent				Calorific value,
Moist	Vol. matter	Fixed carbon	Ash	B.t.u./lb.
10.5	5.4	48.7	35.4	7,190

Size consist, percent

Larger than 1 inch	1 inch by 3/8 inch	Smaller than 3/8 inch
35	40	25

No records are available on the quantity of semicoke produced at this plant.

The Koppers ovens produced semicoke having the following composition:

Analysis of Koppers semicoke

Proximate analysis, percent				Calorific value,
Moist	Vol. matter	Fixed carbon	Ash	B.t.u./lb.
6	6	49	39	7,500

Size consist, percent

Larger than 3/4 inch	3/4 inch by 3/8 inch	3/8 inch by 3/16 inch	Smaller than 3/16 inch
27	34	18	21

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There is no assurance that either of the semicokes analyzed is representative of the coal of the analysis given above, there being no regular program of product control at this plant. No data were available on performance tests of either type of equipment to permit an absolute comparison between the coal used and the products obtained.

Liquid Products. - Tar from the Lurgi carbonizers and the Koppers ovens was mixed and processed in a single plant; thus it is not possible to state the quality from each type. The properties of the liquid products are summarized in table 11. Data on the properties of the crude materials and the refined products are incomplete and consist primarily of information on specific gravity and boiling range. The acids in the distillate of the crude products are relatively high, but no data are available on their content in the original tar.

Incomplete data limit the determination of yield of products. From April 1944 to June 1945, the plant charged 401,437 tons of coal to the Lurgi and Koppers units, while the total products obtained were:

Basis	Bunker fuel oil	Semi-Diesel oil	Gas oil	Motor gasoline	Total
Kiloliters	16,745	1,364	1,609	3,374	23,092
Gallons, thousand	4,424	360	425	891	6,100
Tons	16,729	1,322	1,448	2,740	22,239
Percent by weight	75.3	5.9	6.5	12.3	100.0
Yield, percent of coal charged	4.17	.33	.36	.68	5.54

These yields are much lower than those predicted originally, the Lurgi plant for instance being expected to produce a total of 9.1 percent liquid product. A partial explanation lies in the fact that the Koppers ovens, which carboni more than one-half the coal, have a low inherent yield of tar, also that som of the water gas may be formed partly at the expense of the liquid products, although it is improbable that any appreciable quantity of hydrocarbons is involved. It also appears likely that a part of the coal charged to the plant may have been rejected for ash content, undersize, or other reasons, since the coal available was generally of low quality, but since no specific information was available this factor could not be determined factually.

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TABLE 11. - Properties of liquid products, Teikoku Nenryo Kogyo K.K. - Ube Works

Material	Specific gravity, 15° C.	Boiling range, °C., percent by volume					Percent by volume					Distillate, percent by volume		
		0-170	170-235	235-270	270-350	Residue	Unsaturated	Aromatic	Naphthenic	Paraffinic	Aniline compounds	Acids	Bases	Neutral oils
Precooler tar	1.055	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	28	ND	ND
Tar oil	.979	4.7	9.5	14.8	40.0	31.0	ND	ND	ND	ND	ND	30	3	67
Crude light oil	.962	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	32.0	1.3	66.7
Crude gasoline	.880	29.3	69.2	1.5	0	0	20.5	40.0	39.5	0	ND	5	2	93
Motor gasoline	.812	62.3	37.7	0	0	0	18.1	38.5	16.4	27.0	58.5	ND	ND	ND
Semi-Diesel oil	.969	0	25.2	33.3	36.7	4.8	ND	ND	ND	ND	ND	ND	ND	ND
Bunker fuel oil	.999	0	4.0	14.5	38.3	43.2	ND	ND	ND	ND	ND	ND	ND	ND

ND: No data available.
Source: Company records.

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Gas. - A sample of gas from the offtake of a Lurgi carbonizer at this plant had the following composition:

Composition of Lurgi gas, percent							Calorific value,
CO_2	O_2	H_2	CO	CH_4	CnHm	N_2	B.t.u./cu.ft.
11.6	0.2	6.2	6.4	14.0	1.0	60.6	195

This is almost identical with that at Nissan Ekitai Nenryo and probably represents a period when operation was most satisfactory. The calculated distribution of gas within the unit is shown below:

Distribution of gas in Lurgi carbonizer

Item	Cu. ft./min.	Percent
Cooling gas entering carbonizer	4,530	70.0
Gas burned for carbonizing zone	320	5.0
Unburned gas entering carbonizing zone	150	2.3
Gas burned for drying zone	590	9.1
Excess gas	880	13.6
Total gas leaving oil scrubber	6,470	100.0

For each ton of coal carbonized at the rated capacity of 300 tons per day, approximately 21,800 cubic feet of cooling gas enters the carbonizer. On the same basis, the gas formed per ton of coal is 8,590 cubic feet, of which 4,220 cubic feet is excess and can be withdrawn from the system for use as a fuel gas.

The composition of the gas obtained from the Koppers ovens is:

Composition of Koppers oven gas, percent							Calorific value,
CO_2	O_2	H_2	CO	CH_4	CnHm	N_2	B.t.u./cu. ft.
14.5	0.2	41.5	21.0	14.5	1.3	7.0	390

This analysis is somewhat different from that for usual coke-oven practice, the CO_2 and CO being higher and the CH_4 lower than in regular coke-oven gas. The volume of gas produced is 15,500 cubic feet per metric ton of coal, abou one-fourth greater than for conventional high-temperature ovens, but its lower calorific value, 70 percent of that for coke-oven gas, compensates for this factor.

A comparison of the gas yield from the Lurgi and Koppers units is summarized below:

Comparison, gas yield from Lurgi and Koppers units

Type of carbonizer	Cu. ft. of gas per ton of coal	Calorific value, B.t.u./cu.ft.	B.t.u. in total gas per ton of coal	B.t.u. in gas, percent of B.t.u. in coal charged
Lurgi.....	4,220	195	822,900	3.9
Koppers...	15,500	390	6,045,000	28.8

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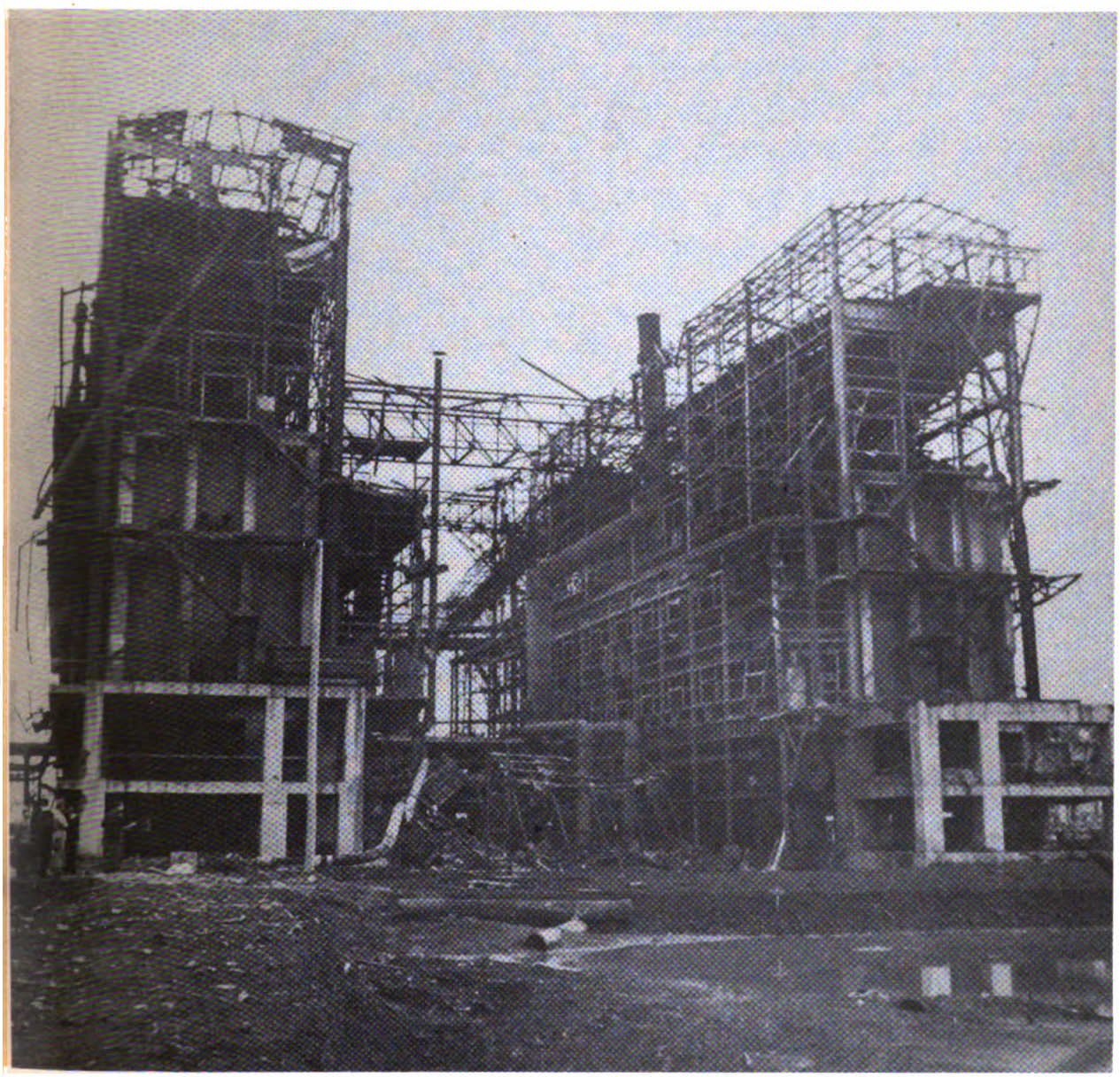

Figure 8. - Koppers continuous vertical ovens at Teikoku Nenryo Kogyo K. K., Ube, Yamaguchi Prefecture.

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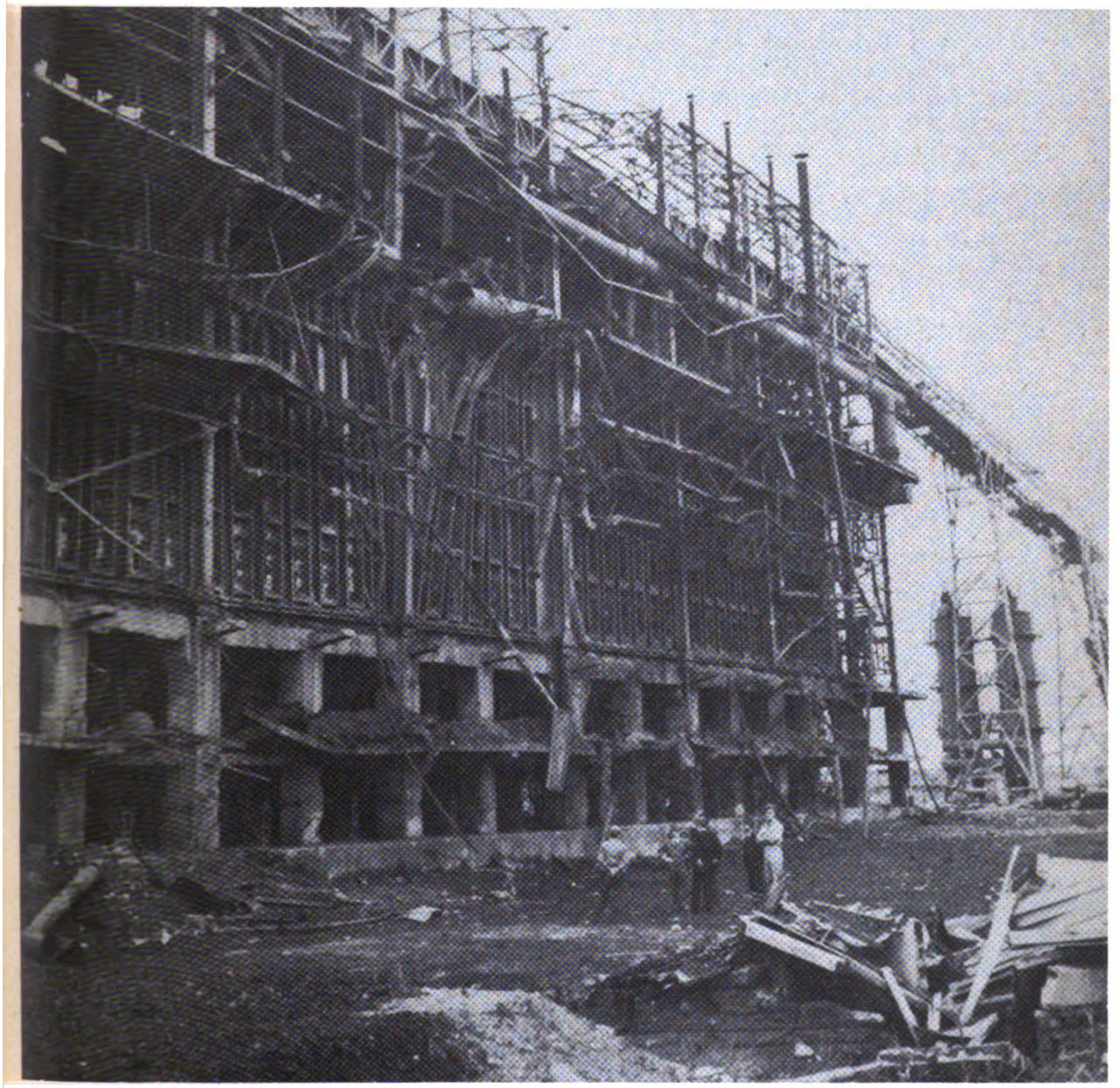

Figure 9. - Koppers continuous vertical ovens at Teikoku Nenryo Kogyo K. K., Ube, Yamaguchi Prefecture.

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The striking difference between the types of units is evident. However, it should be noted that the Lurgi carbonizer is supplying this net output in addition to furnishing the gas required for heating the carbonizer and dryer, whereas the Koppers ovens must be supplied with producer gas for heating the flues to achieve this high gas-production rate.

Other Products. - Crude cresol was produced in small quantities. From April 1944 to June 1945, 687 tons was recovered, maximum production being in April 1944, with 96 tons. Such byproducts are considered unimportant by the operators, semicoke and liquid fuels being most attractive from the profit standpoint.

Costs

Comparative construction costs of the Lurgi and Koppers plants are shown in table 12.

TABLE 12. - Comparison of costs of Lurgi and Koppers carbonization plants

Item	Lurgi		Koppers	
	Equipment	Buildings	Equipment	Buildings
Carbonizers	¥ 7,714,584	¥1,809,611	¥4,413,637	¥ 659,393
Gas producers	-	-	1,001,438	128,246
Electrical apparatus	720,337	52,589	-	-
Coal conveyor	3,173,518	90,480	981,617	289,227
Semicoke handling	1,973,085	52,784	91,356	58,304
Tar recovery	304,999	82,104	505,455	58,092
Blowers	-	-	433,405	71,788
Gas purification	-	-	1,144,959	85,545
Gas holder	-	-	188,666	-
Water cooling	120,449	-	120,873	-
Boiler plant	1,585,334	99,439	-	-
Railway siding	225,997	-	-	-
Warehouses	-	602,790	-	59,864
Misc.	-	-	311,111	-
	¥15,818,303	¥2,789,797	¥9,192,517	¥1,410,459
Total	¥18,608,100		¥10,602,976	

Because the Lurgi plant was charged with the boiler plant, railway siding, and the major part of the coal-handling equipment, its installation cost is inflated compared with that of the Koppers plant. Despite this, the cost per ton of coal carbonized per day at rated capacity is ¥15,500 for the Lurgi plant and ¥17,670 for the Koppers plant.

Present Status

The importance of Ube as an industrial center caused it to be bombed extensively. Four raids essentially destroyed this plant, although damage to the Lurgi carbonizers was only moderate. The Koppers ovens were left standing (figs. 8 and 9), but damage was so great as to necessitate complete rebuilding before they can again be placed in service. The coal-tar processing equipment was a total loss and also must be completely rebuilt.

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The Lurgi plant (fig. 10) will not be repaired, for the operators believe that the cost of imported petroleum will be less than that of liquid fuels made by this process. Because the only coal available locally has an excessively high ash content and low caking power, the semicoke produced is of poor quality and by itself cannot justify future operation of the plant. As the plans of this company are to convert the plant for the production of ammonium sulfate, large quantities of hydrogen will be required. Since, as has been shown, the Koppers ovens are superior to the Lurgi carbonizers for this purpose, they alone will be rebuilt.

Ube Kosan K.K. - Ube Chisso works

Location

The main offices of this company are at No. 1978, Ogushi, Ube, Yamaguchi ken. Like Teikoku Nenryo Kogyo K.K., this plant was built in Ube because of its proximity to the Ube-Onoda coal field.

History

Although intended to produce ammonium sulfate as a major product, an important factor in the design of this plant was the recovery of liquid fuels as a byproduct in generation of the ammonia synthesis gas. Koppers continuous vertical ovens were selected because of their ability to operate satisfactorily with the low-rank coal available, to supply large amounts of gas rich in hydrogen, to produce satisfactory amounts of low-temperature tar, and to furnish semicoke for gas producers for complete gasification of the original coal. Of the same design as those built later at the Ube works of Teikoku Nenryo Kogyo K.K. and illustrated in figure 7, the first bank of Koppers ovens, consisting of 16 chambers, was completed in May 1934, the second bank of 16 chambers in October 1935, and the last bank of 36 chambers in December 1937. The entire installation of 68 chambers operated continuously until the plant was forced to stop because of bomb damage.

Ube Kosan K.K. at present has a nominal capitalization of ¥81,637,500. The ownership of the company rests in 7,919 stockholders, none of whom control more than 10 percent of the stock.

Equipment

Carbonizer. - Being the first of these German-designed units to be built in Japan, the first and second banks of ovens were constructed of silica brick imported from Germany, but the last bank was built with Japanese brick. Ordinary "schamotte" brick was used for the upper flues of all the units. Although the regenerators are of the combined type so that either rich or lean gas can be used for heating, the first two banks are fired only with raw, hot producer gas made from semicoke; the third bank of 36 chambers uses a gas having a calorific value of 290 B.t.u. per cubic foot and recovered from the raw synthesis gas by a Linde-system separator. All regenerators operate on a 30-minute cycle. The rated capacity of the 68 chambers is 600 tons of coal per day, but the maximum actual input obtained for satisfactory performance was about 500 tons per day.

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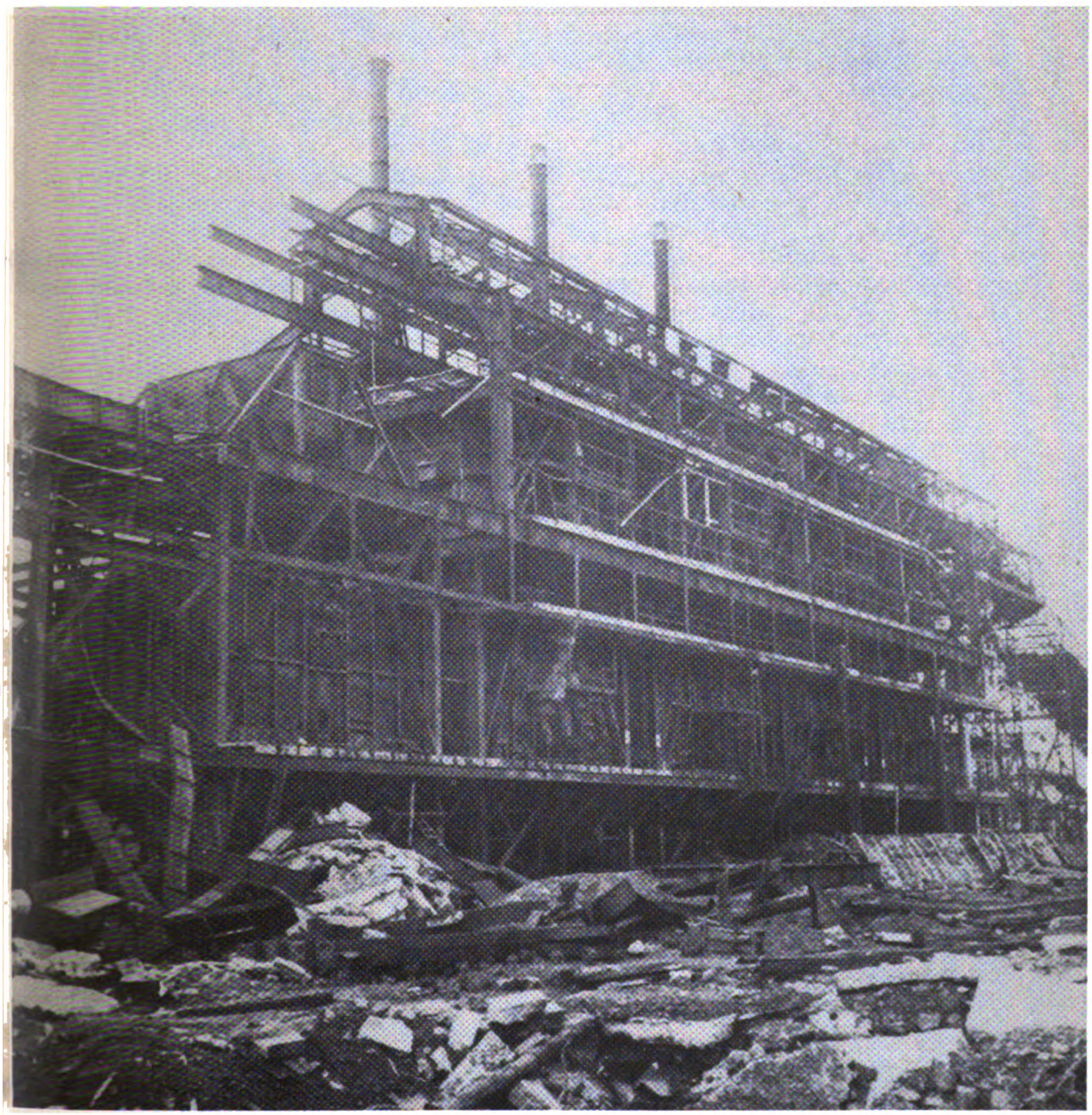

Figure 10. - Lurgi carbonizers at Teikoku Nenryo Kogyo K. K., Ube, Yamaguchi Prefecture.

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Steam is admitted to the bottom of the carbonizing chamber at the rate of 50 percent by weight of the coal charged. Without steam, the gas yield is 7,000 to 10,500 cubic feet per ton of coal; with steam, it is increased to 19,500 cubic feet per ton.

Temperatures in the carbonizer flues range from 850° C. (1,562° F.) at the top to 1,000° C. (1,832° F.) at the bottom. Although no measurement has been made of the actual temperature of the coal charge, the operators estimate the maximum to be 700° C. (1,292° F.).

Tar-Recovery System. - Conventional methods are used for collecting the tar. A large portion is condensed in a hydraulic main and is flushed to a tar sump. A gas-cooling tower 6-1/2 feet in diameter and 30 feet high collects additional tar, while a centrifugal separator followed by a small settling chamber removes the remainder of the tar from the gas. All the tar is drained to a central sump, from where it is pumped to a tank for gravity separation of water, and thence to the tar still. The gas passes to an oil scrubber 10 feet in diameter and 74 feet high, then to an oil separator packed with Raschig rings, to a sulfuric acid washer and a water washer, and to a Thylox plant for sulfur removal and recovery. Next it passes to a final sulfuric acid washer and cooler, and lastly to a dry box for removal of residual sulfur before being stored in a gas holder of 700,000 cubic feet capacity.

Byproduct Processing. - The gasoline plant operates on the German-designed Ibing system. Crude gasoline is stripped from the scrubbing oil by a continuous light-oil still following a heat exchanger, then is pumped to a wash-oil still. The condensate is stored in a tank of 18-ton capacity, from where it is pumped to a motor-driven batch agitator in which it is treated successively with sulfuric acid and caustic soda. Finally, the crude gasoline passes to a plate still, where the motor gasoline is removed and the ends are sent to a naphtha storage tank. Heat exchangers are used freely.

In the tar plant, a storage tank of 2,000-ton capacity feeds a plunger pump which passes the tar through a steam-heated drying tower to remove water. The dry tar is pumped to a heat exchanger and then to a pot still heated with coal, the pitch passing through a cooler to the pitch bay for storage. The vapors flow through the heat exchanger to a water-cooled condenser and thence to receivers for the various fractions, from which they pass to storage tanks.

Both light oil and heavy oil is processed in the same type of plant. Briefly, caustic soda is used to recover phenols, after which the oil is passed to a sulfuric-acid washer and separated into basic-oil and light-oil fractions. The sodium phenolate is pumped to a still, the condensate returning to the caustic soda washer and the residue to a storage tank, from where it is pumped to a carbon dioxide saturator. The liquid then passes to a separating tower where the phenolic oil is recovered, thence through a 30-ton storage tank to a heater, flash tower, and two bubble towers to the final product storage tanks, where light oil, xylenol, cresol, and phenol are retained until shipment.

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The paraffin-recovery plant uses a 75-hp. ammonia compressor to refrigerate brine, the paraffin oil passing through a dryer before being pumped to the first chilling tank. The suspended solid paraffin is removed by a filter press, the heavy oil passing to a 2,000-ton storage tank, the partly dewaxed oil going to a temporary reservoir from where it is returned to the chilling tank as needed, and the crude wax going to the purifying system. Purification consists of treating the wax successively with sulfuric acid, caustic soda, and hot water and pumping it through a sweating pan. The wax fraction is purified further by treating it again with sulfuric acid, washing with hot water, and mixing with infusorial earth. Finally, it passes through another filter press and an infusorial earth filter to a molding machine. The resulting product is white, and its quality appears excellent; its melting point is 45° to 55° C. (113° to 131° F.).

Operating Difficulties

During the period of more than 11 years that this plant has been operating, the principal difficulties have resulted from the formation of clinker on the oven walls. Initial operation of the first bank was attempted with a bottom flue temperature of 1,250° C. (2,282° F.), but at the end of 1 week clinker had completely choked the chambers and it was necessary to reduce the flue temperature to a maximum of 1,000° C. (1,832° F.). Since the pressure in the hopper at the bottom of the chamber is 100 mm. (3.9 inches) water gage, leakage of air is unlikely and the low fusion temperature of the coal ash is considered the limiting factor by the operators. Although clinker continued to form slowly at the lower flue temperature, it could be removed by poking, but this damaged the walls and frequent patching with fire clay was necessary. The development of cracks in the walls and clogging of the regenerators with dust finally made it desirable to rebuild the ovens.

Coal Used

The coal used is from the Okinoyama mine, that from the Itsudan vein being preferred, and is identical with that used in the adjoining low-temperature carbonization plant of Teikoku Nenryo Kogyo K.K. Proximate analyses made over a period of 7 years are given below to show the magnitude of the variations in composition; the ultimate analysis is given of a single sample of coal in November 1936.

Proximate analyses of Okinoyama coal

Date	Percent					Calorific value, B.t.u./lb.
	Moist	Vol. matter	Fixed carbon	Ash	Sulfur	
May 1939...	9.8	38.8	33.4	18.0	1/	10,100
April 1940.	7.9	40.6	36.7	14.8	1/	10,800
March 1941.	10.5	41.6	33.6	14.3	1/	10,100
June 1942..	9.7	36.5	35.2	18.6	1.8	9,360
Oct. 1942..	9.4	37.3	34.1	19.2	1.6	10,100
Aug. 1943..	9.3	38.0	34.4	18.3	1.5	9,200
Oct. 1943..	8.5	40.5	34.2	16.8	1.4	10,100
May 1944...	9.6	40.7	33.6	16.1	1.1	9,650
June 1944..	8.0	40.1	32.0	19.9	1/	9,180
Feb. 1945..	5.7	41.2	34.3	18.8	1/	9,200
May 1946...	6.9	42.6	31.5	19.0	.8	10,000

1/ Data not available.

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Ultimate analysis of Okinoyama coal (November 1936)

Percent							Calorific value, B.t.u./lb.
Moist	H_2	C	N_2	O_2	S	Ash	
10.4	4.4	56.4	0.8	12.8	0.8	14.4	10,120

The classification by rank shows this to be a subbituminous A coal, since it is both weathering and nonagglomerating.

Analysis of Okinoyama coal ash

Percent							Init. def. temp., °C.	Fluid temp., °C.
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Alk.		
51.3	21.9	5.7	8.6	1.8	6.9	3.8	1,010	1,140

Records of the quantity of coal carbonized show that 959,943 tons were charged from 1940 to 1945, a rate of 438 tons per day. This represents continuous operation at 73 percent of capacity.

Products

Semicoke. - The quantity of semicoke produced from 1940 to 1945 was 568,692 tons, a yield of 59.1 percent of the weight of coal charged. Typical analyses of the semicoke over a 10-year period are as follows:

Proximate analyses of semicoke

Date	Percent			
	Moist	Vol. matter	Fixed carbon	Ash
Sept. 1936	6.3	5.2	61.2	27.3
Jan. 1944	7.0	5.4	48.2	39.4
March 1946	6.0	4.5	44.5	45.0

Although the ash content of the coal has not changed appreciably, the semicoke produced in the last few years has had an increasing amount of ash. No definite explanation of this was furnished by the operators, but it is probable that, in the attempt to obtain the greatest possible production of gas in the carbonizers, the quantity of steam used may have been increased over that stated. A slight increase in carbonizing temperature to obtain additional gas at the expense of part of the tar also would have resulted in additional decomposition of the steam added, and consequently greater consumption of semicoke. This, of course, would have caused the ash content of the product to increase.

Liquid Fuels. - The properties of the liquid products obtained are given in table 13.

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TABLE 13. - Properties of liquid products, Ube Kosan K.K.

Material	Specific gravity, 15° C.	Boiling range, °C., percent by volume					°C.		Viscosity Redwood sec. at 50° C.
		0-170	170-235	235-270	275-350	Residue	Freezing point	Flash point	
Crude tar	1.040	1.5	11.4	20.3	45.5	21.3	ND	110	90
Motor gasoline	.795	83.0	17.0	0	0	0	ND	ND	ND
Gas-oil	.882	3.8	41.8	31.9	20.7	1.8	ND	55	ND
Semi-Diesel oil	.953	0	3.7	20.5	50.5	25.3	24	105	47
Bunker fuel oil	.994	0	3.6	10.8	43.4	42.2	ND	108	ND

Material	Percent by volume				Tar acids, percent	Ultimate analysis, percent					Calorific value, B.t.u./lb.
	Unsaturated	Aromatic	Naphthenic	Paraffinic		H_2	C	N_2	O_2	S	
Crude tar	ND	ND	ND	ND	30.0	10.0	76.8	0.6	12.0	0.6	17,250
Motor gasoline	26.5	30.8	24.9	17.8	ND	ND	ND	ND	ND	ND	ND
Gas-oil	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Semi-Diesel oil	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bunker fuel oil	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND: No data available.
Source: Company records.

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The yield of liquid products is reported in detail in table 6. Maximum production of gasoline was in 1940 with 1,630 KL (430,613 gallons) output. Variations in refining practice caused the amount of gas oil, semi-Diesel oil, and bunker fuel to fluctuate somewhat although the total output per year varied only between 8,894 KL and 11,961 KL (2.3 million gallons and 3.2 million gallons). As in other low-temperature carbonization plants, bunker fuel oil made up about half the output. The distribution of the products for the past 6 years is shown below:

Distribution of liquid products

Year	Basis	Bunker fuel oil	Semi-Diesel oil	Gas oil	Motor gasoline	Total
1940	KL	5,473	2,414	0	1,630	9,517
	Gallons, thousand	1,446	638	0	431	2,515
	Percent	57.5	25.4	0	17.1	100.0
1941	KL	5,362	3,410	599	1,450	10,821
	Gallons, thousand	1,417	901	158	383	2,859
	Percent	49.7	31.4	5.5	13.4	100.0
1942	KL	6,399	3,369	952	1,240	11,961
	Gallons, thousand	1,690	890	252	328	3,160
	Percent	53.4	28.2	8.0	10.4	100.0
1943	KL	2,738	4,563	1,066	1,129	9,496
	Gallons, thousand	723	1,205	282	298	2,508
	Percent	28.8	48.1	11.2	11.9	100.0
1944	KL	4,313	4,032	1,305	1,174	10,824
	Gallons, thousand	1,139	1,065	345	310	2,859
	Percent	39.9	37.2	12.0	10.9	100.0
1945	KL	1,648	808	209	142	2,807
	Gallons, thousand	435	213	55	38	731
	Percent	58.7	28.8	7.4	5.1	100.0
Weighted average, percent		46.8	33.6	7.4	12.2	100.0

For the period 1940 to 1945, the following relationship existed between the liquid products formed and the quantity of coal carbonized:

Yield of liquid products, 1940-45

Basis	Bunker fuel oil	Semi-Diesel oil	Gas oil	Motor gasoline	Total
KL	37,661	24,228	4,132	8,226	74,247
Gallons, thousand	9,949	6,401	1,092	2,173	19,615
Tons	37,435	23,089	3,636	6,581	70,741
Percent by weight	52.9	37.7	5.1	9.3	100.0
Yield, percent of coal charged	3.90	2.41	.38	.69	7.38

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Considering the quantity of gas produced by these carbonizers and the high temperatures at which they operate, this yield of liquid products is considered satisfactory. The estimated yields of intermediate and final liquid products shown below are considered by the engineers of the plant to be representative of actual performance.

Estimated yields of intermediate and final liquid products

Basis: Raw coal = 100 percent.

Intermediate products		Final products	
Item	Percent	Item	Percent
Low-temperature tar	8.0	Motor gasoline	0.6
Crude gasoline	.8	Pitch	1.79
Paraffin oil	3.12	Paraffin	.12
Middle oil	1.72	Bunker fuel oil	1.56
Crude light oil	1.4	Semi-Diesel oil	2.36
Crude paraffin	.24	Gas-oil	.74
Crude heavy oil	4.28	High phenol oil	.12
Crude phenols	.64	Cresol	.26

Gas. - A gas balance made in January 1946 showed that with an input of 12,367 tons of coal and 6,183 tons of steam to the Koppers ovens, a total of 251,500,000 cubic feet of gas was produced. This is at the rate of 20,400 cubic feet per ton of coal. The gas formed had the following composition:

Composition of Koppers-oven gas

Percent					Calorific value, B.t.u./ cu. ft.
CO_2	H_2	CO	CH_4	N_2	
15.6	38.0	18.4	16.0	12.0	345

Based on an assumed calorific value for the coal of 10,000 B.t.u. per pound the gas produced is equivalent to 32 percent of the heat in the coal charge. This high rate of gasification confirms the explanation given above for the high ash content of the semicoke.

Costs

The costs of construction of the Koppers ovens are as follows:

	Construction costs, Koppers ovens		
	Bank		
	1	2	3
No. of chambers	16	16	36
Date of completion	May 1934	Oct. 1935	Dec. 1937
Cost:			
Buildings	¥ 61,201	¥ 60,389	¥ 127,000
Ovens	533,534	459,455	696,050
Accessory equipment	1,011,074	846,403	2,092,891
Subtotal	¥1,605,809	¥1,366,247	¥2,915,941
Total			¥5,887,997

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This cost is slightly more than half that of the more recent Koppers plant of Teikoku Nenryo Kogyo K.K., placed in operation during 1942. The gradually decreasing value of the yen may have been partly responsible for this difference, although the increased cost of the later plant undoubtedly resulted from wasteful practices commensurate with an economy geared to war levels.

Present Status

Damage to the Koppers ovens was slight through bombing, although other units of the plant were destroyed or partly burned. The ammonium sulfate plant at present is able to function only at a very low level, consequently, gas from the Koppers ovens is not required in large quantities and the opportunity is being taken to rebuild the ovens for future service. As a result, one bank is in operating condition, and the other two are being rebuilt. In May 1946 repair of one bank was 50-percent completed. All three banks will be replaced in operating condition as rapidly as possible.

Osaka Gasu K.K. - Seimi works

Location

The plant was located at Kawagishico 1-31, Konohana-ku, Osaka, Osaka-ken

History

As the low-temperature carbonization equipment was dismantled in 1930, the plant could not be seen. The information reported was obtained in an interview with Dr. A. Shimomura, son of the inventor of the process.

The objective of the plant was to manufacture a special grade of semicoke as a substitute for imported low-volatile coking coals used in the production of metallurgical coke. Since this company had been producing coke since 1898, the opportunity of replacing imported coal with a domestic material produced in its own plant was eagerly sought. Semicoke for blending should contain 15 to 25 percent volatile matter and should be of about the same size consist as the coal with which it is mixed; thus the Shimomura process used at this plant was designed with this end in view.

A trial plant using this method was installed in the Iwasaki works of the company in April 1922 and operated until December 1923. In September 1923 a similar plant was erected at the Seimi works and was later expanded to include a more recent design, including a rearrangement of dual carbonizers to increase their capacity. However, because of general mechanical troubles and financial difficulties, the low-temperature carbonization plant was dismantled in 1930.

Equipment

A description has already been given of the stationary, horizontal, externally heated, cast-iron retort with high-speed internal agitation; the

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general arrangement of the equipment is shown in figure 11. The design capacity of the carbonizer varies according to the nature of the coal but is usually 3.5 to 8 tons per day for each retort. The coal tar was recovered in three water-cooled condensers; no special processing equipment was installed for refining the tar, which was added to that obtained from the high-temperature coke ovens at the same plant.

Operating difficulties

Operating difficulties consisted primarily of failure of the cast-iron retort through overheating. Although the temperature of the coal nominally was not allowed to exceed 500° C. (932° F.) gradual accumulation of coke on the inside walls of the retort decreased the rate of heat transfer to the point where, to maintain adequate output, it was necessary to operate the retorts at metal temperatures as high as 800° C. (1,472° F.). Under these conditions the retorts failed through warping, their life being too short to justify the cost involved. To prevent this trouble the retorts were scraped and cleaned to remove the adherent carbon, but the intervals between cleanings were so brief that operation was too discontinuous to be satisfactory.

A heat balance based on performance over a period of good operation follows. The computation is based on the carbonization of 1 pound of coal with a calorific value of 13,150 B.t.u.

Heat balance, Shimomura retort

Output			
Product	Yield, lb. per lb. of coal	B.t.u.	Percent of B.t.u. in coal
Semicoke	0.715	9,250	70.4
Heavy tar	.071	1,300	9.9
Light tar	.030	578	4.4
Gas	1/2.38	1,835	13.9
Subtotal		12,963	98.6
Unaccounted for		187	1.4
Total		13,150	100.0

1/ Cubic feet per lb. of coal.

Coal Used

Strongly caking coal from the Yubari mine in the Ishikari field, Hokkaido, was commonly used. This coal had the following composition:

Composition of Yubari coal

Proximate analysis, percent				Calorific value, B.t.u./lb.
Moist	Vol. matter	Fixed carbon	Ash	
0	42.9	48.8	8.3	13,200

It is classed as a high-volatile A bituminous coal. Production data on the quantity of coal carbonized are not available, but from 1923 until 1926 abou

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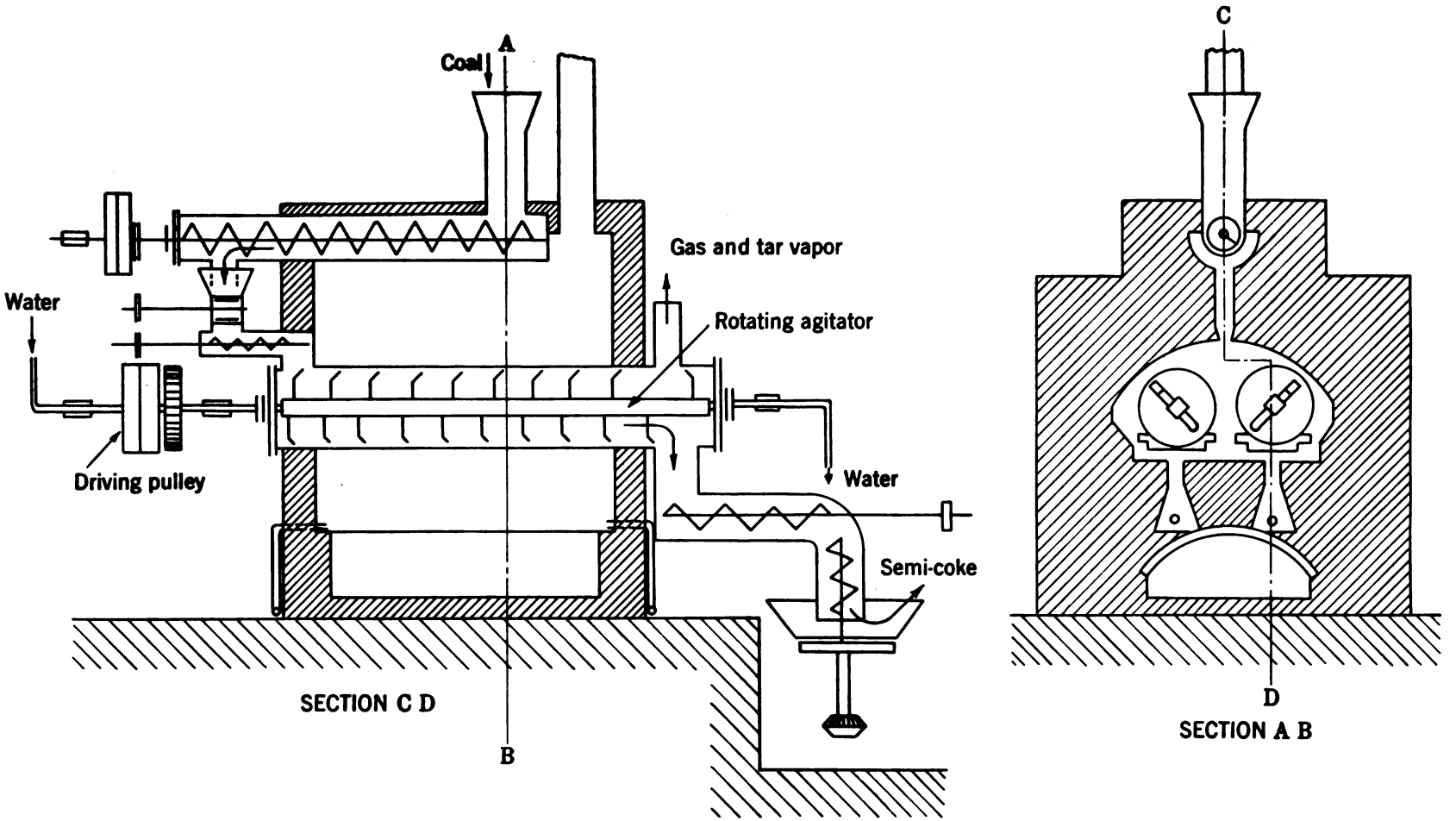

Figure 11. - Shimomura retort for low-temperature carbonization of coal, as used at Osaka Gasu K. K., Seimi works.

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700 tons of coal was used. Since the plant operated sporadically, the actual capacity of the carbonizers cannot be determined.

Products

Semicoke. - The quantity of semicoke produced over the 4-year period noted was approximately 500 tons, a yield of about 70 percent. When Yubari coal was carbonized, the semicoke had the following composition:

Composition of Shimomura semicoke

Proximate analysis, percent				Calorific value,
Moist	Vol. matter	Fixed carbon	Ash	B.t.u./lb.
0	16.9	72.6	10.5	12,950

Size consist, percent		
Larger than 3/4 inch	3/4 inch by 1/4 inch	Smaller than 1/4 inch
2.9	12.4	84.7

The apparent specific gravity of the semicoke was 1.009, and its true specific gravity 1.524, from which the porosity was calculated to be 34 percent. According to Dr. Shimomura, it was well-suited for blending purposes.

Liquid Fuels. - The tar recovered as a byproduct was collected from three water-cooled condensers. Its analysis is given below:

Composition of low-temperature tar

Item	Condenser		
	No. 1	No. 2	No. 3
Specific gravity, 15° C.	0.985	0.962	0.950
Viscosity, Engler seconds at 50° C.	90	72	72
Calorific value, B.t.u./lb.	18,250	18,520	19,150
Sulfur, percent	0.34	0.50	0.69
Free carbon, percent	.19	.02	.03
Flash point, °C.	72	46	39
Yield, percent of coal carbonized	7	2	1

At the time this plant was operated, low-temperature tar had not yet been developed as a source of liquid fuels. In addition, the small quantity of tar produced in this semicommercial plant did not warrant installing special processing equipment. That produced was utilized principally for cleaning gas mains in high-temperature coke ovens, a small amount injected with the gas dissolving adhering naphthalene and thus cleaning the main with a minimum of trouble. Small amounts were also used in the ammonium sulfate plant, where adding small quantities of low-temperature tar to the saturator gave a whiter product. Tests were also made on the use of this tar for carburetting water-gas but no commercial application resulted.

Gas. - The gas produced in the Shimomura retort had the following composition:

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Composition of gas

Percent							Calorific value,
CO_2	O_2	H_2	CO	CH_4	C_nH_m	N_2	B.t.u./cu. ft.
5.6	0.4	23.6	6.3	29.9	17.9	16.3	771

The yield was approximately 5,230 cubic feet per ton of coal when the plant was operating properly; under these conditions, 13.9 percent of the latent heat in the coal appeared in the gas.

The daily gas consumption for heating the carbonizer was about 26,000 cubic feet, while 18,000 cubic feet per day was used in the gas engine driving the rotating agitator. At this rate, 8.4 tons of coal would require carbonizing to supply the daily gas requirements of the plant. Since this input could not be maintained, it was necessary to supply gas from an external source, and therefore no net gas was obtained from the process. As a result, a modified design was proposed to permit heating the retort with coke or other solid fuels.

Costs

No cost data are available. High maintenance expense, small output and no financial return from the tar prevented profitable operation.

Present Status

No further studies of low-temperature carbonization were made by this company after the plant was dismantled. At that time, importation of low-volatile coking coal from North China had reached a satisfactory level, while that from Manchuria was available in quantity a few years later. As a result, the necessity of using semicoke as a low-volatile blending agent largely was removed, and the incentive for operating the plant was less powerful. Under an economy where importation of coking coal is limited, this process might be revived. Advances in the refining of coal tar and more favorable prices for liquid fuel, combined with better engineering design and improved materials of construction, might permit operation of the process at a profit. Fundamentally, however, the use of strongly caking coal in any internally agitated carbonizer can be expected to result in operating difficulties such that a wide margin of profit should be allowed to compensate for unexpected emergencies.

Toho Kagaku Kogyo K.K.

Location

Although not adjacent to any major coal fields, Nagoya is important as an industrial center. The plant was situated at Atsuta-mae, Minato-ku, Nagoya, Aichi-ken, because of its proximity to a large group of ultimate consumers.

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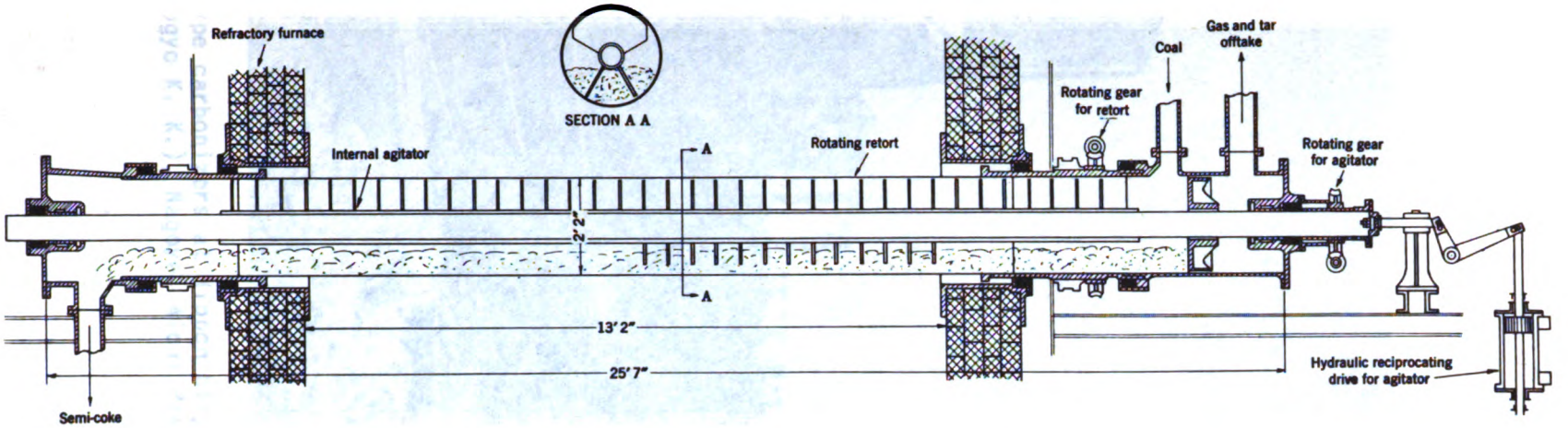

Figure 12. - Retort and agitator for Mimura low-temperature carbonizer at Toho Kagaku Kogyo K. K., Nagoya, Aichi Prefecture.

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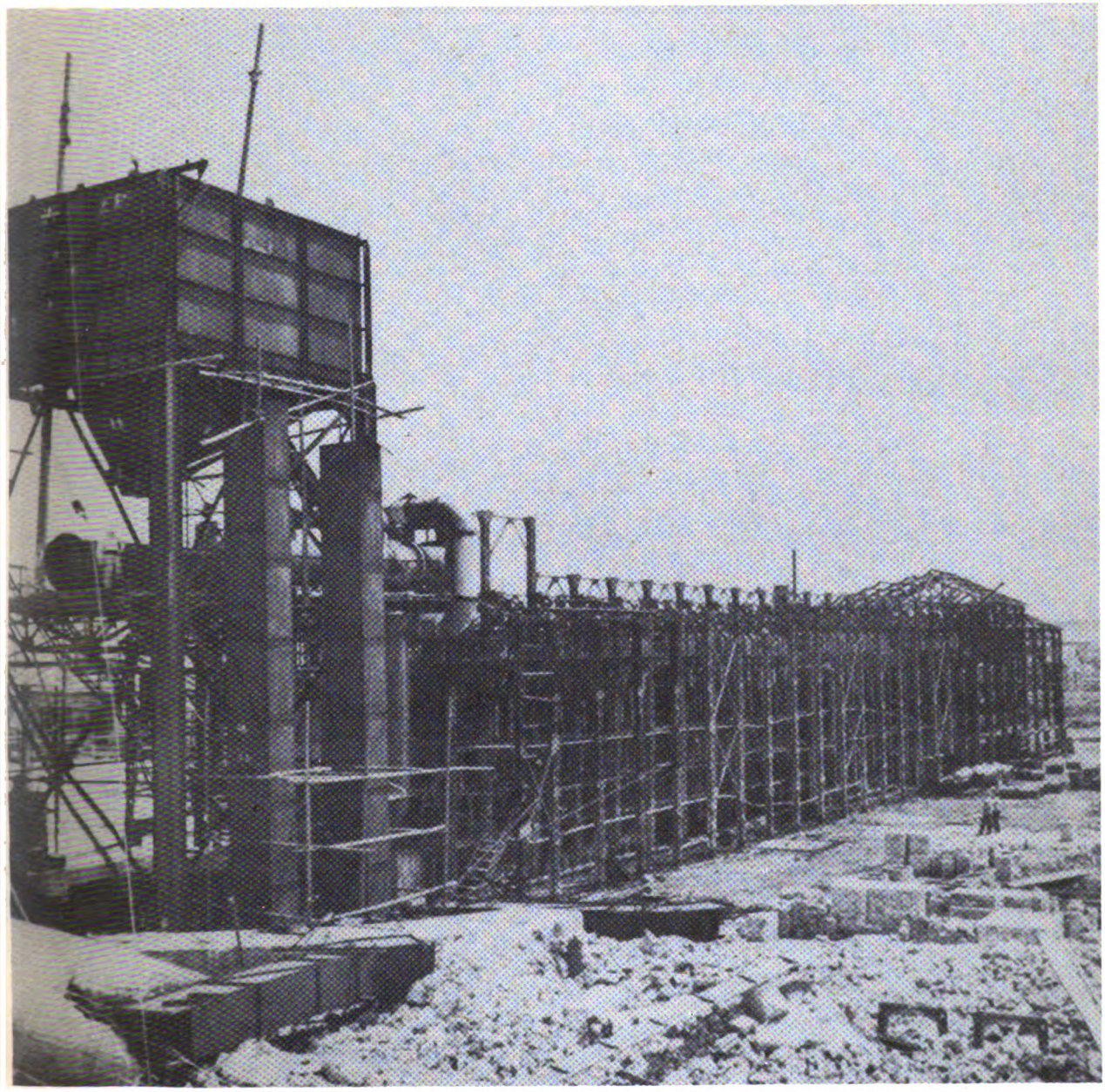

Figure 13. - Mimura-type carbonizers at Nippon Hiryo Kogyo K. K. (formerly Toho Kagaku Kogyo K. K.), Nagoya, Aichi Prefecture.

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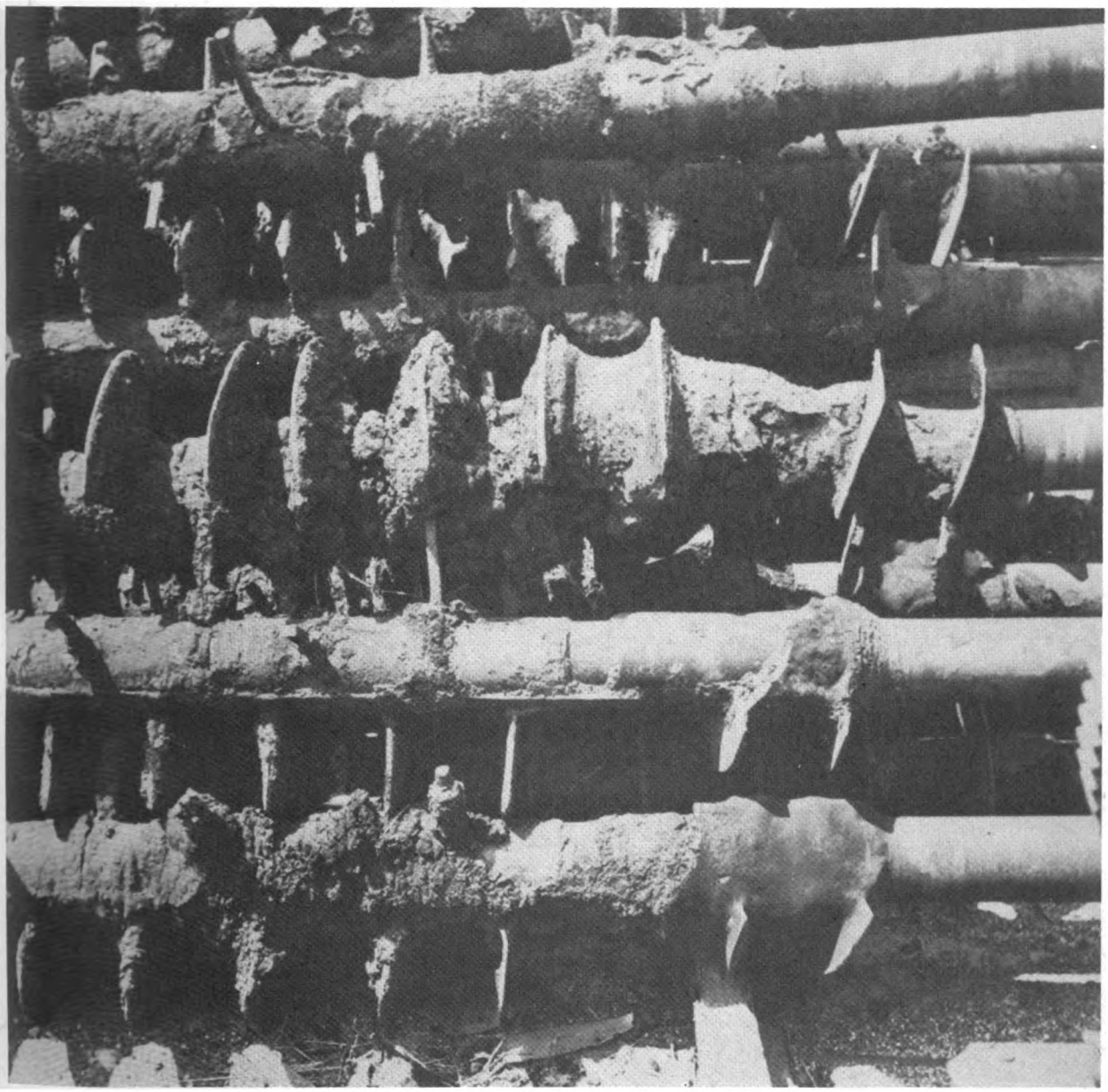

Figure 14. - Internal agitators removed from Mimura retorts at Nippon Hiryo Kogyo K. K. (formerly Toho Kagaku Kogyo K. K.).

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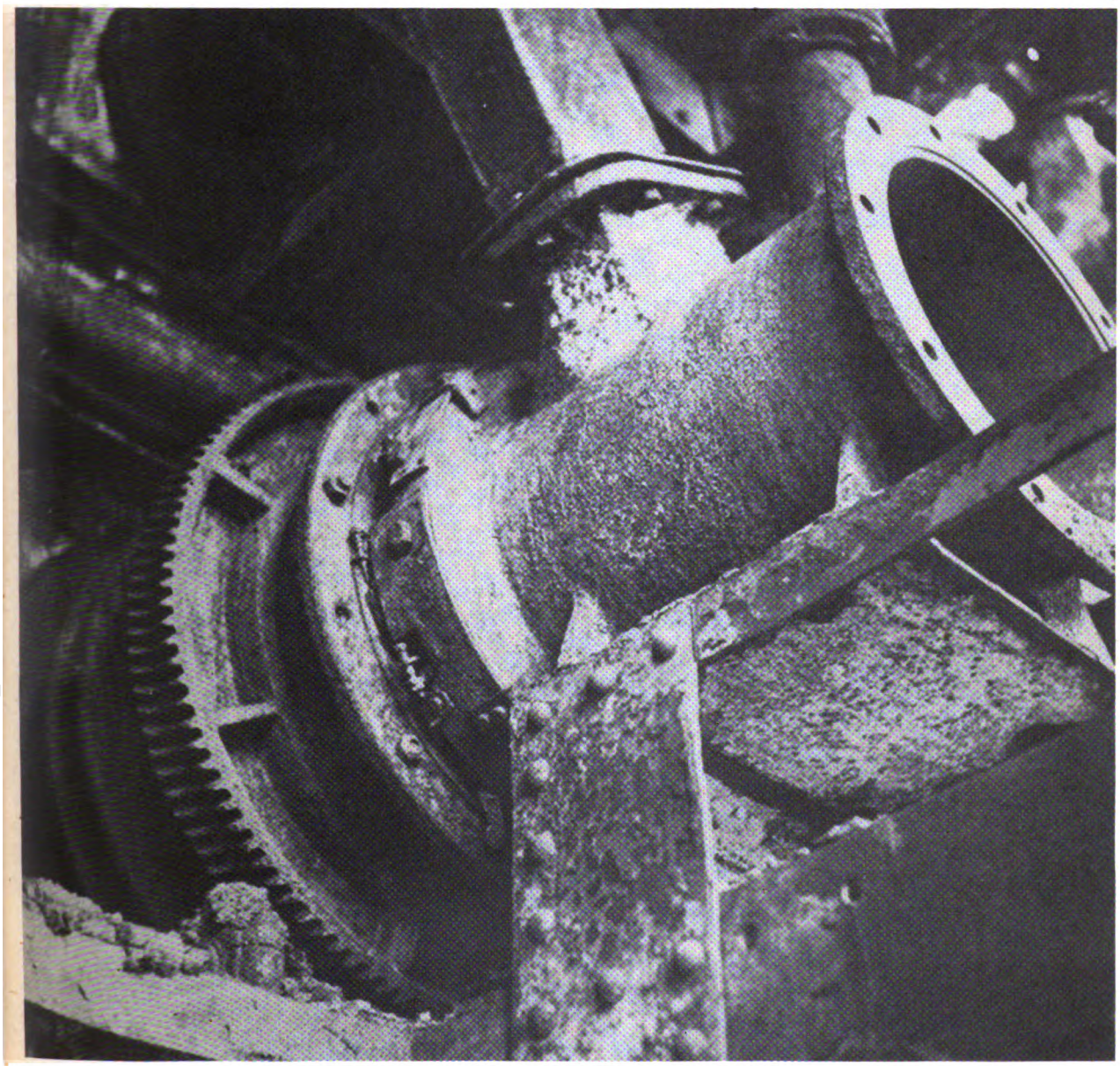

Figure 15. - End of Mimura retort at Nippon Hiryo Kogyo K. K. (formerly Toho Kagaku Kogyo K. K.), showing rotating gear and gas offtake.

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History

Incorporated in May 1938 with a capitalization of ¥50,000,000 and owned entirely by Toho Gasu Kaisha, this plant was intended to produce synthetic liquid fuels by the hydrogenation of low-temperature tar. Mimura retorts were to be used as the source of tar, 120 retorts being installed with an expected total capacity of 300 tons of coal per day. Construction of the carbonization plant was finished in October 1940, but successful operation of the accompanying hydrogenation system was not achieved, with the result that a refining plant was installed to process the low-temperature tar directly to liquid fuels. In June 1945 the plant was taken over by the Japanese navy and operated as the Second Naval Fuel Depot of the Navy Fuel Board. Activity ceased with the close of the war, and in November 1945 the company was absorbed by Nippon Hiryo Kogyo K.K. Established in 1940 as a distribution agency for inorganic fertilizers, Nippon Hiryo Kogyo K.K. was capitalized at ¥50,000,000, with the Japanese Government holding half the stock and private investors the remainder. Postwar plans for converting the plant to the production of ammonium sulfate call for abandonment of the low-temperature carbonization units, which were being dismantled in May 1946. Coke-oven gas from the nearby plant of Toho Gasu Kaisha and water gas made from coke originating in the same plant will be adequate to produce the expected output of 40,000 tons of ammonium sulfate annually.

Equipment

Carbonizer. - The Mimura carbonizer has been described adequately in an earlier part of this report. Briefly, it consists of an externally heated rotating retort fabricated from mild steel, with counter-rotating horizontally oscillating rabble arms connected to a concentric shaft. The retort and agitator assembly is shown in figure 12 and views in figures 13 to 15. Normal carbonizing temperature is 500° C. (932° F.).

Tar-Recovery System. - A hydraulic main at the top of the carbonizers collects a major part of the tar, which flows directly to the tar pool. Tar remaining in the gas is removed successively by two water-cooled condensers, a centrifugal tar separator, the exhauster, and a third cooler, all of the tar passing to the same pool, where it is separated from water and pumped to the tar-storage tank. After leaving the last cooler the gas passes through an oil scrubber, then to a caustic soda scrubbing tower where tar acids are removed, through a double dry box for sulfur removal, and finally to the station gas holder.

Byproduct Processing. - Crude low-temperature tar, after passing through a heat exchanger, is further heated to remove water, light oil being recovered from the condensate by gravity separation. The dry tar passes to a gas-heated pipe still; crude light oil is recovered directly, while the ends pass to a final pipe still with a flashing tower and fractionating column, from which crude light oil and middle oil are obtained. Ends from the flashing tower are given temporary storage in a 50-KL (13,200-gallon) tank and finally are pumped to a pot still, where the heavy oil is recovered. The pitch remaining is cooled and pumped to the pitch bay.

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The crude light oil is scrubbed with sulfuric acid, then caustic soda and sent to a gas-heated pipe still where motor gasoline is recovered. The ends from the fractionating column are further separated in another pipe still to give kerosine and finished light oil.

Crude middle oil is washed with caustic soda, the sodium phenolate solution being mixed with that from the light oil and acidified with sulfuric acid to release the tar acids. A pot still then separates the mixture into cresol and xylenol, and tar acid with a boiling point above 225° C. (437° F.).

Operating Difficulties

The use of a strongly caking coal resulted in masses of semicoke adhering to the rabble arms of the internal agitator, thus freezing it in the retort. Attempts to move the agitator under such conditions caused bending of the arms and failure of the agitator shaft. Even with only moderately caking coals, semicoke packed between the blades of the agitator and prevented movement of the charge; thus, attempts to obtain successful operation by slight preoxidation of the coal during prolonged drying, blending of coal or variations in speed of rotation or of carbonizing temperature had little beneficial effect.

Leakage of air into the combustion space surrounding the retorts allowed local overheating to occur, the air:fuel ratio being disturbed, with the result that temperatures of the metal parts sometimes exceeded 700° C. (1,292° F.). Since all metal parts were of mild steel, the life of the retorts and agitators never exceeded 150 days, while failure sometimes occurred within 15 days of being placed in service. The retorts usually failed at welded joints.

Warping of a retort induced by uneven heating caused leakage of the byproduct gas through the end seals, particularly with the upper retort, which was under a static pressure of 1 inch water gage. This gas usually ignited, with resulting damage to the mechanical equipment driving the retort and agitator. The lower retort was at a negative pressure of 2 inches water gage, with the result that air leaked into the retort through the seal and allowed part of the gas to burn. Many attempts were made to redesign these seals to prevent leakage but without success, the retort itself being insufficiently rigid to prevent warpage under the temperature conditions imposed.

The mechanical driving equipment was too complicated for this application. Multiple driving units made it necessary to shut down an entire bank of retorts to stop one for repairs, while the hydraulic actuators for the horizontal movement of the internal agitators were inadequate. Insufficient space between retorts made repair work difficult. Because of jamming of the internal agitator, uncontrolled air leakage into the combustion chamber, warping of the retort, leakage of rotating end seals, and general mechanical difficulties, not more than 80 retorts of the 120 installed were ever in operation at one time. Although the daily capacity of the plant had been

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expected to be 300 tons of coal per day, under the best conditions only 82 tons per day could be carbonized.

Coal Used

Despite the troubles caused by their use, only strongly caking coals were carbonized in these retorts. According to the engineers, such coals continued to be used because of the increased reactivity of the semicoke and the greater yield of tar and gas per ton of coal. The larger over-all output possible for the plant by using weakly caking coal at a higher input in tons per day was not acceptable to the operators, who insisted on using the type of coal for which the plant supposedly had been designed.

Coal used regularly was from the Oyubari and Yubari mines in the Ishikari coal field, Hokkaido, and from the Nissaku mine in Karafuto. This latter coal was less strongly caking than the Hokkaido coals and was used in blends to the extent of 30 to 50 percent; no substantial difference in operation was noted when these blends were carbonized, the coal still being too strongly caking for this type of equipment. Analyses of the coals used follow:

Proximate analysis of coals used

Kind	Percent			
	Moist	Vol. matter	Fixed carbon	Ash
Oyubari	1.1	40.6	51.6	6.7
Yubari	1.2	42.8	49.8	6.2
Nissaku	4.3	42.5	46.0	7.2

Classification of these coals is not possible, since data on their calorific value are not available; because of the high content of volatile matter, they probably should be classed as high-volatile B bituminous coals.

The quantity of coal carbonized each year is included in table 6. Maximum input was in 1942 with 29,971 tons of coal for the year, thus the maximum average carbonization rate is 82 tons of coal per day.

Products

Semicoke. - The quality of the semicoke varied widely, particularly with respect to ash content. The analyses following show the composition of three typical samples, although the source of the coal being carbonized at that time is not available:

Proximate analyses of semicoke

Sample	Percent			
	Moist	Vol. matter	Fixed carbon	Ash
a	1.1	8.7	83.4	6.8
b	2.5	10.4	73.4	13.7
c	.6	13.7	59.7	26.0

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Size consist of semicoke

Larger than 1 inch	1 inch by 3/4 inch	3/4 inch by 3/8 inch	Smaller than 3/8 inch
10	28	25	37

It could not be determined definitely whether the ash content of sample c was high because of excessive ash in the coal or because of combustion occuring within the retort. As the quality of the coal is most likely to change, this factor is probably responsible.

Semicoke production was at a maximum in 1942, when 19,652 tons was produced, a yield of 65.6 percent. During the entire life of the plant 71,925 tons of semicoke was produced from 107,019 tons of coal, a yield of 67.2 percent.

Semicoke in sizes larger than 1 inch, making up 10 percent of the output, was sold as domestic fuel to replace charcoal. The size between 1 inch and 3/4 inch was also sold partly for this purpose, as well as for use in gas producers. All of the semicoke in the range 3/4 inch by 3/8 inch was gasified, while that smaller than 3/8 inch was briquetted.

Liquid Products. - Properties of the liquid products are shown in table 14.

Only small quantities of gasoline were obtained in this plant, production being noted only in 1941. Like other low-temperature carbonization plants, the principal liquid fuel produced was bunker fuel oil, as shown in the following tabulation of liquid fuels and their yield, in terms of the quantity of coal carbonized for the entire life of the plant.

Distribution and yield of liquid products

Basis	Bunker fuel oil	Gas oil	Motor gasoline	Cresol	Xylenol	High-boiling tar acids	Total
Kiloliters...	2,501	811	4	-	-	-	3,316
Gallons, thousand...	661	214	1	-	-	-	876
Tons	2,628	718	3	179	112	33	3,673
Percent by weight	71.4	19.6	0.1	4.9	3.1	0.9	100.0
Yield, percent of coal charged ...	2.46	.67	.00	.17	.10	.03	3.43

The low efficiency represented by a total yield of liquid products of only 3.43 percent is evidence of the unsatisfactory performance of this plant.

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TABLE 14. - Properties of liquid products, Toho Kagaku Kogyo K.K.

Material	Specific gravity, 15° C.	Boiling range, °C., percent by volume					Flash point, °C.	Viscosity, Redwood sec., 50° C.	Residual carbon, percent	Tar acids, percent	Melting point, °C.
		0-170	170-235	235-270	270-350	Residue					
Crude tar	1.056	0.7	18.3	15.0	41.0	25.0	ND	ND	ND	ND	ND
Motor gasoline	.828	91.0	9.0	0	0	0	ND	ND	ND	ND	ND
Gas oil	.885	7.4	70.4	16.5	5.7	0	64	ND	ND	ND	ND
Semi-Diesel oil ...	.945	7.4	41.6	11.4	39.6	0	61	32	0.6	10	ND
Bunker fuel oil ...	1.051	0	9.9	18.8	42.3	29.0	102	160	11.1	25	ND
Pitch	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	120
Cresol	1.032	7	93	0	0	0	ND	ND	ND	ND	ND
Xylenol	1.027	6	94	0	0	0	ND	ND	ND	ND	ND
High-boiling tar acid	1.020	5	73	12	10	0	ND	ND	ND	ND	91

ND: No data available.
Source: Company records.

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Gas. - Although not operated primarily as a source of gas, the gas obtained from this installation was of greater importance than the liquid products. Composition of the gas for four samples taken at unspecified times was as follows:

Composition of gas from Mimura retort

Sample	Percent							Calorific value, B.t.u./ cu. ft.
	CO_2	O_2	H_2	CO	CH_4	C_nH_m	N_2	
a	5.1	4.2	5.6	5.3	28.1	4.5	47.2	442
b	5.0	4.2	4.7	5.1	29.0	4.5	47.5	459
c	6.0	2.3	1.1	5.3	31.2	4.4	49.7	472
d	4.6	4.1	2.3	3.5	33.1	5.0	47.2	490
Average	5.2	3.7	3.5	4.8	30.4	4.6	47.8	466

Leakage of air into the retorts is evidenced by the large proportion of nitrogen in the gas. Coke-oven gas normally contains less than 8 percent nitrogen and has a calorific value of about 580 B.t.u. per cubic foot.

Data available on the total amount of gas produced each year permit calculation of the yield of gas per ton of coal, as follows:

Gas produced per ton of coal

Year	Gas produced, cubic feet	Coal charged, tons	Gas, cu. ft. per ton of coal	Heat in gas, percent of heat in coal charged 1/
1940	46,009,000	6,759	6,800	12.0
1941	270,686,000	24,903	10,900	19.2
1942	251,336,000	29,971	8,400	14.8
1943	199,148,000	29,874	7,700	13.5
1944	119,383,000	19,330	6,200	10.9

1/ For 466 B.t.u./cu.ft. of gas and 12,000 B.t.u./lb. of coal.

Although more than the yield from the Lurgi carbonizers, the heat in the gas formed is less than half that of the Koppers continuous vertical ovens.

Other Products. - The quantity of pitch, cresol, xylenol, and high-boiling tar acids produced was insignificant. The total production of pitch was 2,652 tons for the 5 years of operation, while only 324 tons of the other products was recovered during the same period.

Costs

Exact construction costs of the plant were not available. The best estimates were ¥3,000,000 for the carbonizers and ¥2,000,000 for the tar recovery and processing plant. At 82 tons of coal per day, or 29,900 tons per year, this represents an investment cost of ¥167 per ton of annual capacity, approximately four times greater than the Lurgi carbonizer.

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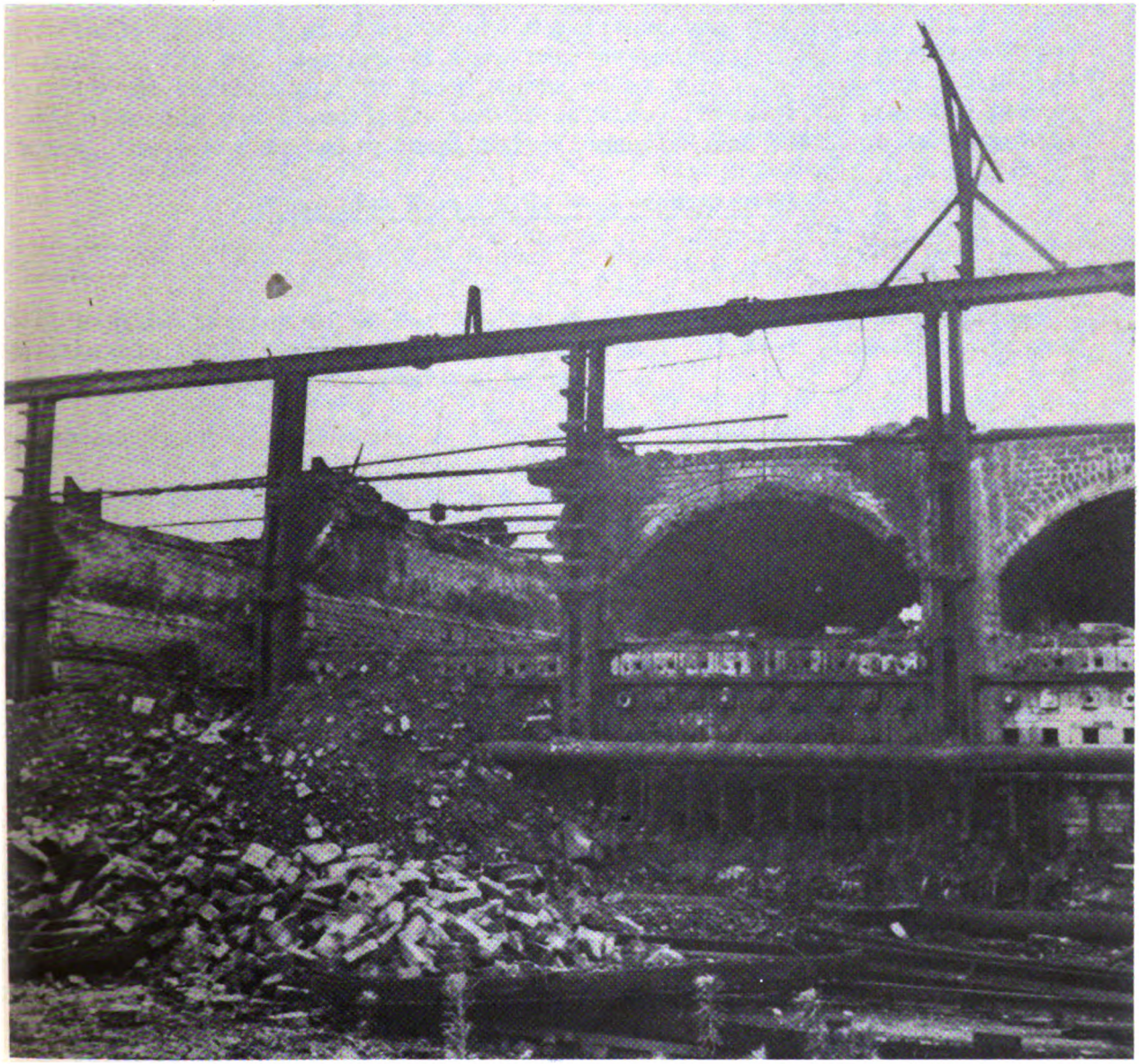

Figure 16. - Damaged Knowles ovens at Nihon Yuka Kogyo K. K., Kawasaki. Kanagawa Prefecture.

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Present Status

Although operating difficulties had been great, the plant was maintained in service throughout the war until a severe earthquake in December 1944, which caused major property damage and great loss of life in Nagoya, destroyed parts of the plant. The fire-brick structure surrounding the retorts was so badly cracked that control of temperature was impossible, while misalignment of the end bearings of some retorts prevented their further use. Following the earthquake, the plant operated at very low capacity until incendiary bombing put it entirely out of service. Because of its poor performance, the plant is being completely dismantled and will not be rebuilt.

Nihon Yuka Kogyo K.K. - Kawasaki works

Location

The plant is located at No. 34, Ogi-machi, Kawasaki-shi, Kanagawa-ken, approximately midway between Tokyo and Yokohama. It is in the center of one of the most industrialized areas of Japan.

History

Founded in January 1935 with a capital of ¥1,500,000, the original objective of this company was the production of liquid fuels and industrial chemicals from coal tar by distillation in pot stills and by hydrogenation of the residue. At that time there was no intention to produce tar, which was to be purchased from high-temperature coke plants in the Tokyo area. However, in March 1936, the plans were expanded to include production of coke and of coal tar, and the capitalization was increased to ¥3,000,000. A contract was made in February 1937 with an American engineering firm whereby the patent rights to the Knowles system of carbonization was obtained for the Orient, and in July 1937 the capitalization was increased to ¥10,000,000 to finance the construction of a battery of Knowles ovens (see fig. 16). By July 1939 two experimental ovens were completed, and following a successful series of tests the decision was made to install a full-scale plant of 60 ovens. However, a prior agreement with Showa Denko K.K. whereby that company had agreed to purchase semicoke for the generation of water gas was abrogated; thus only 30 ovens were built, construction starting in September 1940. Shortages of materials and the onset of the war delayed construction, so that the last of the ovens was not completed until January 1943.

Actually, of the 30 ovens built, only 5 were placed in service carbonizing coal. Lack of adequate coal supplies prevented greater use of the installation, the coal capacity for all the ovens totaling 140,000 tons per year. Since the availability of coal during the war was not expected to improve, an order was issued by the Army in March 1943 moving the entire installation of Knowles ovens to Kailang, North China, where metallurgical coke was to be made. However, since the Knowles ovens were suitable for the production of pitch coke needed badly for electrodes, the company succeeded in retaining 15 ovens for this purpose. The carbonization of pitch was begun in October 1943 and continued until July 1945, when the plant was destroyed by bombing.

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Hydrogenation of coal tar was never satisfactorily accomplished, thus removing one original objective for constructing the plant. Instead, hydrogenation of kerosine to produce aviation gasoline was done on a limited scale with the equipment available.

Equipment

The Knowles ovens have been described in a previous part of this report; construction followed exactly the plans furnished from the United States. The general arrangement of flues and of other details is shown in figures 17 and 18. All refractories were of Japanese make, the floor tiles of the ovens used for carbonizing coal being silica brick while those for pitch were of silicon carbide. Neither of these brick were of good quality, the silica brick being almost black when fired while the silicon carbide appeared to contain an unusually large amount of a clay binder. Other brick used in constructing the ovens were "schamotte," a high-alumina fire brick.

The temperature of the air leaving the regenerators was maintained as closely as possible at 1,100° C. (2,012° F.), and the regenerators were operated on a 30-minute cycle. The surface of the floor tile was kept at 1,150°C. (2,102° F.). A charge of coal weighed 7-1/2 tons and when leveled was about 12 inches deep; the carbonizing time normally was 14 to 15 hours. With coal-tar pitch the charge was 8 tons and was 8 inches deep when melted, while 12 hours was required to complete its carbonization.

Coal tar from the ovens was processed in four simple pot stills. Because of the small amount of tar obtained from the operation of only five ovens, no involved tar recovery or processing equipment was installed.

Operating Difficulties

Operating difficulties were minor. Principally, they consisted of accumulations of carbon on the floor tiles when carbonizing pitch, this carbon requiring removal by scraping to maintain satisfactory rates of heat transfer Damage to the silica brick was severe under these conditions, and it was necessary to use silicon carbide brick for this application. The life of the silicon carbide floor tiles was 1 year when carbonizing pitch. "Pushing" the semicoke was no problem, but was difficult with the pitch coke because of adherence to the floor. Leakage of molten pitch around the edges of the doors was negligible.

Coal Used

Coals from a wide variety of sources were carbonized in the experimental ovens during the period 1939 to 1943, both alone and in blends. The followin table shows the composition of three typical coals.

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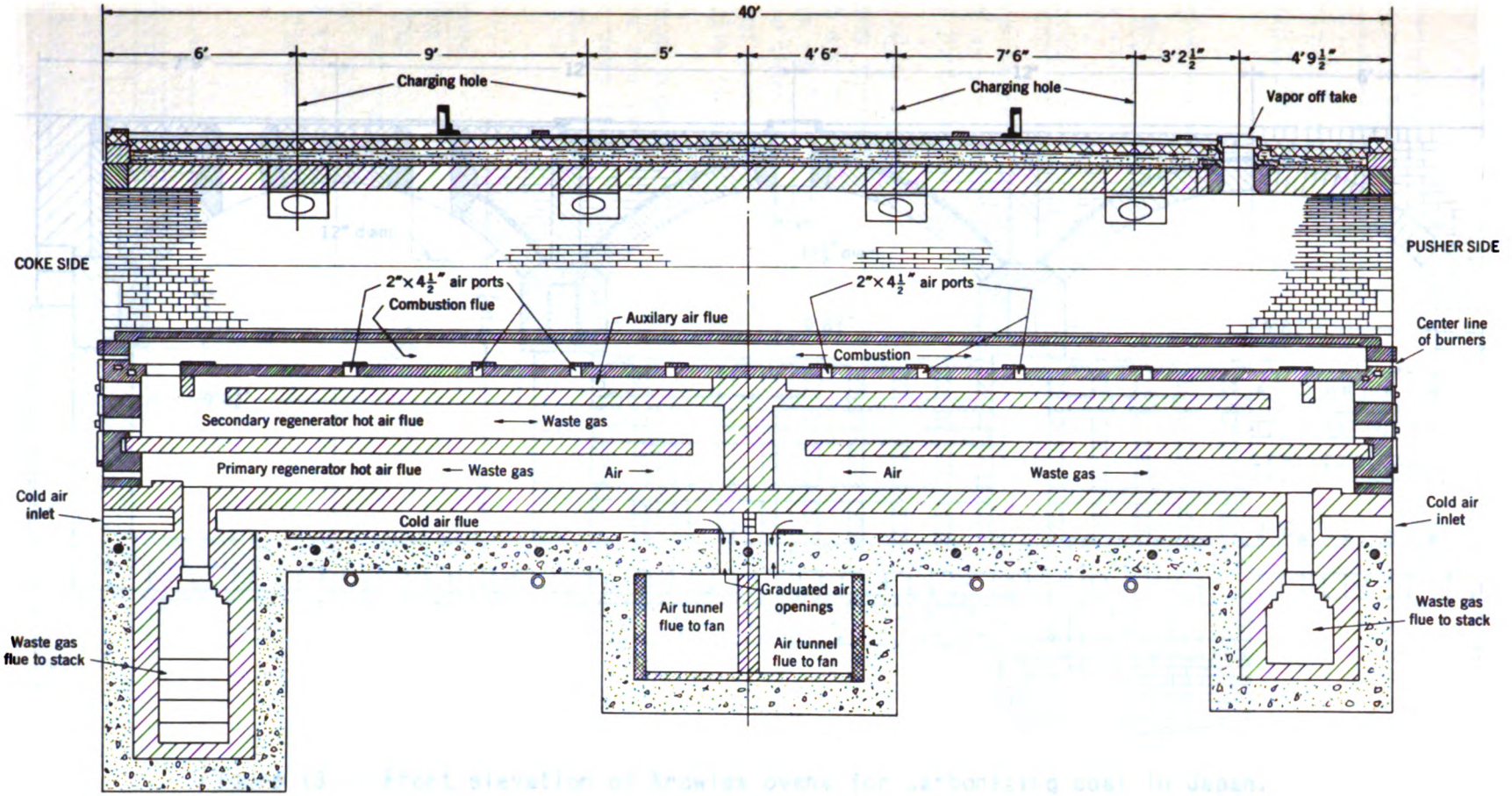

Figure 17. - Side elevation of Knowles ovens for carbonizing coal in Japan.

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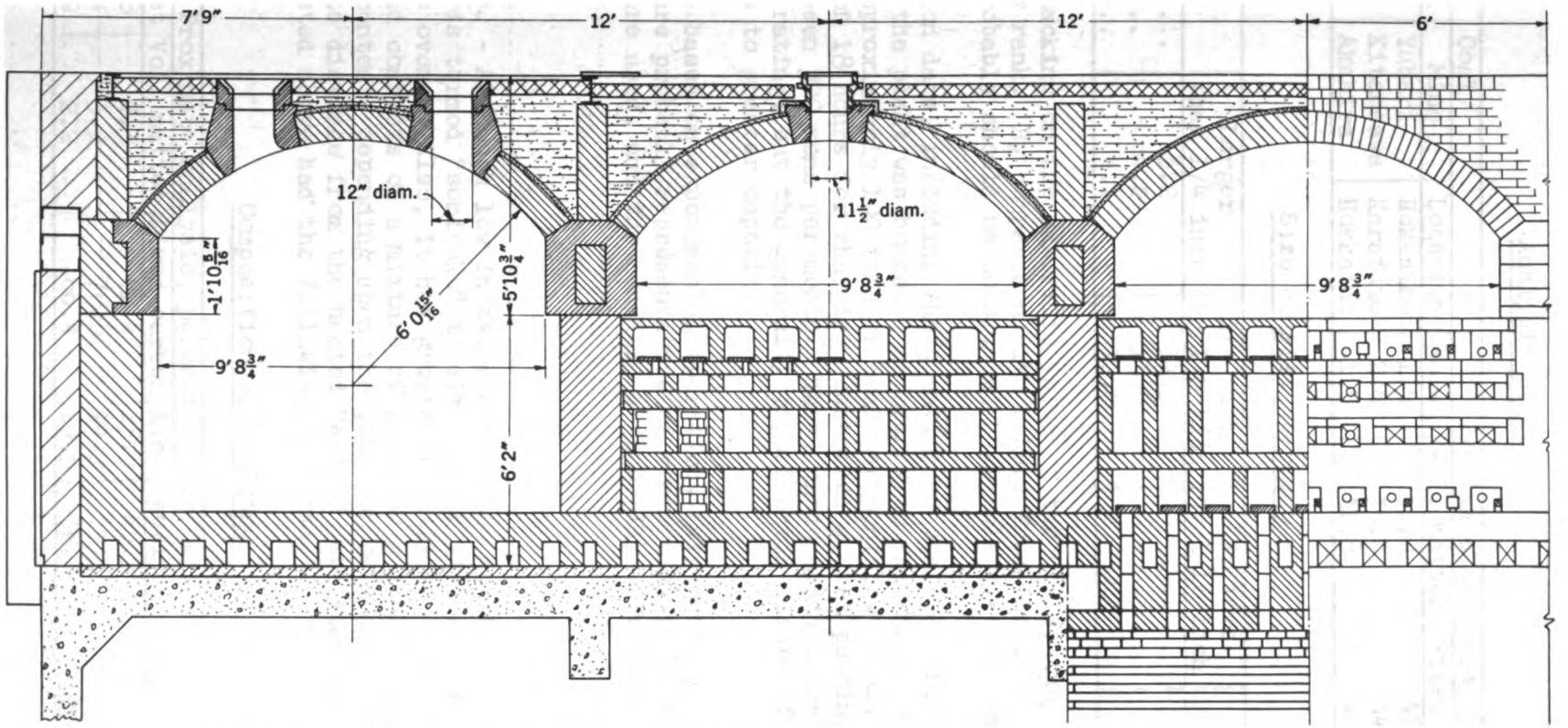

Figure 18. - Front elevation of Knowles ovens for carbonizing coal in Japan.

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Analysis of coal

Coal			Proximate analysis, percent			
No.	Mine	Location	Moist	Vol. matter	Fixed carbon	Ash
1	Yubari	Hokkaido	1.5	41.0	48.9	8.6
2	Kitaosawa	Karafuto	2.6	33.0	54.4	10.0
3	Akahira	Hokkaido	1.5	31.8	44.7	22.0

Size consist, percent

Coal No.	Larger than 1/4 inch	1/4 inch by 1/8 inch	1/8 inch by 1/16 inch	Smaller than 1/16 inch
1	5.2	14.5	29.0	51.3
2	4.2	13.4	29.5	52.9
3	4.1	12.8	30.0	53.1

As data are lacking on the calorific value of the coals, they cannot be classified by rank. By comparison with others from the same general location, they probably should be considered high-volatile A bituminous coals.

Production data, including the quantity of coal carbonized, were destroyed when the plant was bombed. According to the engineers, each oven carbonized approximately 100 tons of coal per month, whereas, based on a total cycle of 18 hours for charging, carbonizing, and pushing, the input should have been 300 tons per month. Thus, these ovens operated at only one-third of rating, but the generally experimental nature of the plant was not conducive to greater capacity.

Although based on experimental operation, both these data and those that follow are probably representative of commercial performance. Full-size ovens were used, and the conditions generally were those of an operating plant.

Products

Semicoke. - Although low in average volatile matter, the main product of the ovens is termed "semicoke" to distinguish it from coke made in vertical slot-type ovens. Also, it has greater reactivity than usual high-temperature coke and consists of a mixture of products having widely varying volatile matter content, depending upon the position of a given particle in the charge and its distance from the heated "sole." The semicoke produced from the coals listed above had the following properties:

Composition of Semicoke

Coal No.	Proximate analysis, percent				Porosity, percent	Coking conditions	
	Moist	Vol. matter	Fixed carbon	Ash		Temp., °C.	Time, hr.
1	0.8	2.3	81.4	15.5	48.5	1,215	14.9
2	2.4	3.9	78.8	14.9	55.3	1,270	15.5
3	1.9	2.2	66.4	29.5	38.0	1,290	13.3

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Size consist, percent

Coal No.	Semicoke yield, percent	Larger than 1/2 inch	1-1/2 inch by 1/2 inch	Smaller than 1/2 inch	Drum index	
					Knowles	Slot oven
1	67.5	94.5	3.3	2.2	61.3	48.8
2	67.4	85.3	5.7	9.0	70.0	64.2
3	82.7	93.1	4.5	2.4	85.6	84.2

In the drum test a sample of coke is rotated in a standard drum at 15 r.p.m. for 2 minutes. The coke is then removed and sieved, the amount larger than 16 mm. expressed as percentage of the weight of the sample being taken as a measure of strength and termed the "drum index." The best metallurgical coke is expected to have a drum index of 85 to 90. Although two of these cokes do not meet this requirement, those produced in the Knowles ovens are stronger than the cokes made in conventional vertical slot ovens from the same coals, the difference being greater as the caking tendency of the coal decreases.

Approximately 10,000 tons of pitch coke was produced from October 1943 to July 1945. When carbonizing pitch, the products were, approximately, 50 percent pitch coke, 25 percent pitch oil, and 25 percent gas.

Liquid Products. - No data are available on the properties of the products refined from the coal tar, although the small quantities produced are listed in table 6. The properties of the raw coal tar are as follows:

Composition of coal tar

Coal No.	Yield, percent of coal charged	Sp. gr., 15° C.	Boiling range, °C., percent				Residue	Tar acids, percent
			0-170	170-235	235-270	270-350		
1....	7.8	1.092	3.6	10.8	17.6	42.7	25.3	-
2....	7.3	1.094	4.6	10.4	14.4	41.2	29.4	7.4
3....	8.3	1.087	6.5	13.5	16.3	38.1	25.6	8.8

There is no essential difference in the three tars, which, in general, are intermediate in nature between true low-temperature tar and that obtained from conventional high-temperature slot ovens. The quantity of tar acids is typical of a medium-temperature process. The boiling range, however, is more indicative of low-temperature tar, the residue being small while the lower boiling fractions are relatively large.

Gas. - The composition of the gas from the Knowles ovens when carbonizing the three coals listed above is as follows:

Composition of gas

Coal No.	Percent							Calorific value, B.t.u./cu. ft.
	CO_2	O_2	H_2	CO	CH_4	CnHm	N_2	
1	2.4	0.4	45.3	6.0	34.3	4.7	6.9	620
2	2.3	.5	49.2	5.4	31.8	4.5	6.3	600
3	2.1	.4	47.7	6.5	30.2	5.4	7.7	605

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Coal No.	Gas, cu. ft./ton of coal			Yield, percent of total gas made
	Gross output	Reqd. for heating	Net yield	
1	10,350	4,590	5,760	55.6
2	ND	ND	ND	ND
3	9,890	4,240	5,650	57.1

ND: No data available.

The gas is identical in composition with that from byproduct coke ovens, while the total amount of gas produced is also comparable. However, because of increased heat loss, the consumption of heating gas is greater than with vertical slot ovens, thus the net yield of gas is less.

Present Status

The installation of Knowles ovens at this plant was 90 percent destroyed by bombing. Much of the refractories can be reclaimed; but auxiliary apparatus, such as that for coal handling, the leveler and pusher, piping, and electrical equipment, must be entirely replaced. Because of the satisfactory performance of the ovens and the high quality of the coke they produced from Japanese coals, the ovens will be rebuilt if permitted and if suitable financial arrangements can be made. However, no decision has been reached as yet by the company regarding its field of activity in the future.

Tokyo Gasu K.K. - Tsurumi works

Location

The plant was located at Anzen-cho, 1-1, Tsurumi-ku, Kanagawa-ken, in the same industrial area as the Nihon Yuka Kogyo plant just described.

History

Tokyo Gasu K.K. was one of the early companies in Japan to install high-temperature byproduct coke ovens as a source of gas, 20 Koppers ovens being built at the Sunimachi works in 1919. The Tsurumi works is more recent, with 72 byproduct ovens built in 1930 and 48 ovens added in 1941. Because of the demand for liquid fuels in the years preceding the war, it was decided to install a low-temperature carbonization unit to supplement the tar already being obtained from the high-temperature ovens, and in 1938 construction was started on a plant of 240 retorts designed by S. Mimura, then an engineer of this company. Because of the necessity for haste, no adequate testing of the design was attempted, and the plant was laid out full-scale in 10 benches of 24 retorts each. The design, which originated in this plant, was identical with that of Toho Kagaku Kogyo K.K. in Nagoya, which has already been described in considerable detail. The first 5 benches of 120 retorts were placed in operation in 1940 but gave so much trouble that the remaining 5 benches were not completed. By 1943 it was evident that the process was not suitable for strongly caking coals; and rather than attempt to continue operation using coals of less caking power, the project was terminated and the plant dismantled. Much of the equipment, consisting of retorts and carbonizing apparatus, was sold to Toho Kagaku Kogyo, which was still attempting

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to operate its plant; the remainder was consigned to other coke plants for miscellaneous uses, much of it being sent to Karafuto, although there is no record of its eventual use. Dismantling of the plant was completed by the end of 1943.

Equipment

The design of the equipment and the operating difficulties were the same as those already described for Toho Kagaku Kogyo K.K. The accumulation of large masses of semicoke in the retort was most objectionable, since it resulted in jamming the agitator and necessitated stopping the unit for cleaning. Warping of the retorts and leakage of the end seals also were annoying, while inability to heat the retorts uniformly was a constant source of trouble. Mechanical difficulties with the driving equipment often interrupted otherwise satisfactory operation. Also, because one motor drove the agitators for 40 retorts, trouble in any one retort in that system made it necessary to stop the others. As the result of these difficulties, all 120 retorts were never in operation simultaneously, only about 80 retorts usually being in serviceable condition at one time.

Coal Used

Because all the records pertaining to this plant were destroyed when the plant was dismantled, no analyses could be obtained of the coal carbonized. Data from another source showed that 6,188 tons of coal was carbonized during the 3 years the plant was in service; maximum input was believed to be 90 tons per day. According to the engineers at the plant, the coal was from the Yubari mine in Hokkaido and thus was strongly caking. No weakly caking coals were used, but attempts were made to decrease the caking tendency of the Yubari coal by passing it through an internally heated rotating drum at 200° C. (392° F.). This "thermodyzing" treatment was ineffective, probably because sufficient time was not allowed to achieve adequate surface oxidation, but details on the conditions of the treatment were not known.

Products

Analysis of the semicoke was not available, but it was said to be unsuitable for portable gas producers because of its high content of volatile matter. However, it was used successfully as domestic fuel in place of charcoal. The total amount of semicoke produced was stated to be 4,108 tons, a yield of 66.4 percent of the coal carbonized.

The properties of the tar or its yields on refining could not be obtained, but 557 tons was produced in all; thus 9.0 percent of the weight of the coal was recovered as low-temperature tar. Despite the difficulties in operation, this represents a considerably greater recovery than was obtained at Toho Kagaku Kogyo K.K.

No information could be obtained on either the quality or the volume of gas produced, or on the volume of gas required to heat the carbonizer.

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Costs

As an estimate, the cost of the carbonization plant was ¥4,000,000, not including equipment for processing the tar. At 4,300 tons of coal per year, the actual maximum capacity obtained, the investment cost would be ¥930 per ton of annual capacity, approximately 19 times greater than for the Lurgi carbonizers at Nissan Ekitai Nenryo K.K. The disparagement between these costs indicates the unsuitability of the process as a satisfactory or profitable means of carbonizing strongly caking coals.

Present Status

The engineers of this company stated that the entire operation of the carbonizers had been a "nightmare" and that they were relieved when the decision finally was made to abandon the plant. Even operating data were destroyed, since they were considered too humiliating to be retained as a matter of record. Because of the complete failure of this plant, it is unlikely that any further activity on low-temperature carbonization will be attempted by Tokyo Gasu K.K.

Nippon Seitetsu K.K. - Wanishi works

Location

This plant is at the site of the largest steel plant in northern Japan, at Muroran, Hokkaido.

History

Originally established in 1909 as the Wanishi Seitetsu K.K., this company was merged with others in 1934 in a move by the Japanese Government to consolidate the entire steel industry under state control. The new company, Nippon Seitetsu K.K., was capitalized in 1934 at ¥359,821,000, of which ¥284,195,000 was owned by the Government. Production of the company in 1934 accounted for 96 percent of the pig iron, 53 percent of the steel ingots, and 44 percent of the steel products made in Japan. At present, the total capitalization is stated to be ¥800,000,000.

Because of the importance of coke in the metallurgy of steel, considerable attention has been paid to the production of coke solely from Japanese coals. Although high-volatile coking coals are available both in Kyushu and Hokkaido, the low-volatile coals needed for blending to produce satisfactory metallurgical coke have not been obtainable other than by importation, usually from North China. In the attempt to place the industry on a self-sustaining basis, the substitution of semicoke for low-volatile coal was studied intensively, and in 1936 a low-temperature carbonization plant was installed at Wanishi for the production of such semicoke. This plant operated successfully until the end of the war, when it was forced out of operation, together with much of the other equipment of the plant, by restrictions imposed by the occupational forces and by lack of adequate coal supplies.

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Equipment

Although stated by the plant engineers to be a Japanese development, since it was designed and built without outside assistance, the Wanishi low-temperature carbonizers are patterned closely after the Thyssen retort originally constructed in Germany. The mechanical features of the externally heated, rotating, horizontal, cylindrical retort with internal spiral flange have been satisfactory, and no unusual difficulties have been experienced during operation. Figure 19 shows the general arrangement of a carbonizer and its associated dryer.

The carbonizers usually are stopped once a year for about 1 month for cleaning, when accumulated tar and dust are removed, and general repairs made. Except for this annually scheduled outage, no interruptions to operation normally occur. In this plant, four carbonizers were installed, each with a separate heating furnace; but only three were operated at a time, one being retained as a spare. The expected capacity of each carbonizer was 100 tons per day, thus the normal capacity of the plant was 300 tons of coal per day.

Because of the greater expected yield of gasoline, the tar-recovery and processing systems are separate from those already available for the vertical slot ovens also installed at this plant. Originally, the gases leaving the carbonizers passed through a Cottrell precipitator for removing tar mist and dust, but adequate provisions had not been made for cleaning so that accumulations of dust and tar prevented satisfactory operation. Substitution of a hot cyclone-type dust separator solved this problem satisfactorily. After leaving the dust separator, the gases pass through cooling towers, where most of the tar is recovered, and then to water-spray towers before entering the oil scrubber. From the scrubber the gas flows into a small gas holder before being pumped into the gas mains of the plant.

The scrubbing oil passes through heat exchangers to a continuous heater and a fractionating column, where the stripped oil is returned to the scrubber through the heat exchanger and a cooler. The crude light oil, leaving approximately at 93° C. (199° F.), also passes through the heat exchangers and enters a tank, from which it flows as needed through a sulfuric acid scrubber to the final still, where motor gasoline is recovered.

The tar obtained from the initial coolers and that separated from the water in the spray towers is stored in tanks until needed. Distillation is in a triple cascade pot still, from which tar light oil is sent to the crude light-oil storage tank, middle oil to the wash oil tank, and heavy oil to storage. Pitch is sent directly to the pitch bay. A flow sheet for processing the low-temperature tar is shown in figure 20.

Coal Used

Because of the type of the retort, only noncaking coals have been carbonized at Wanishi, for it was well realized that caking coals would build up into masses of semicoke and clog the retort. Further, because the semicoke

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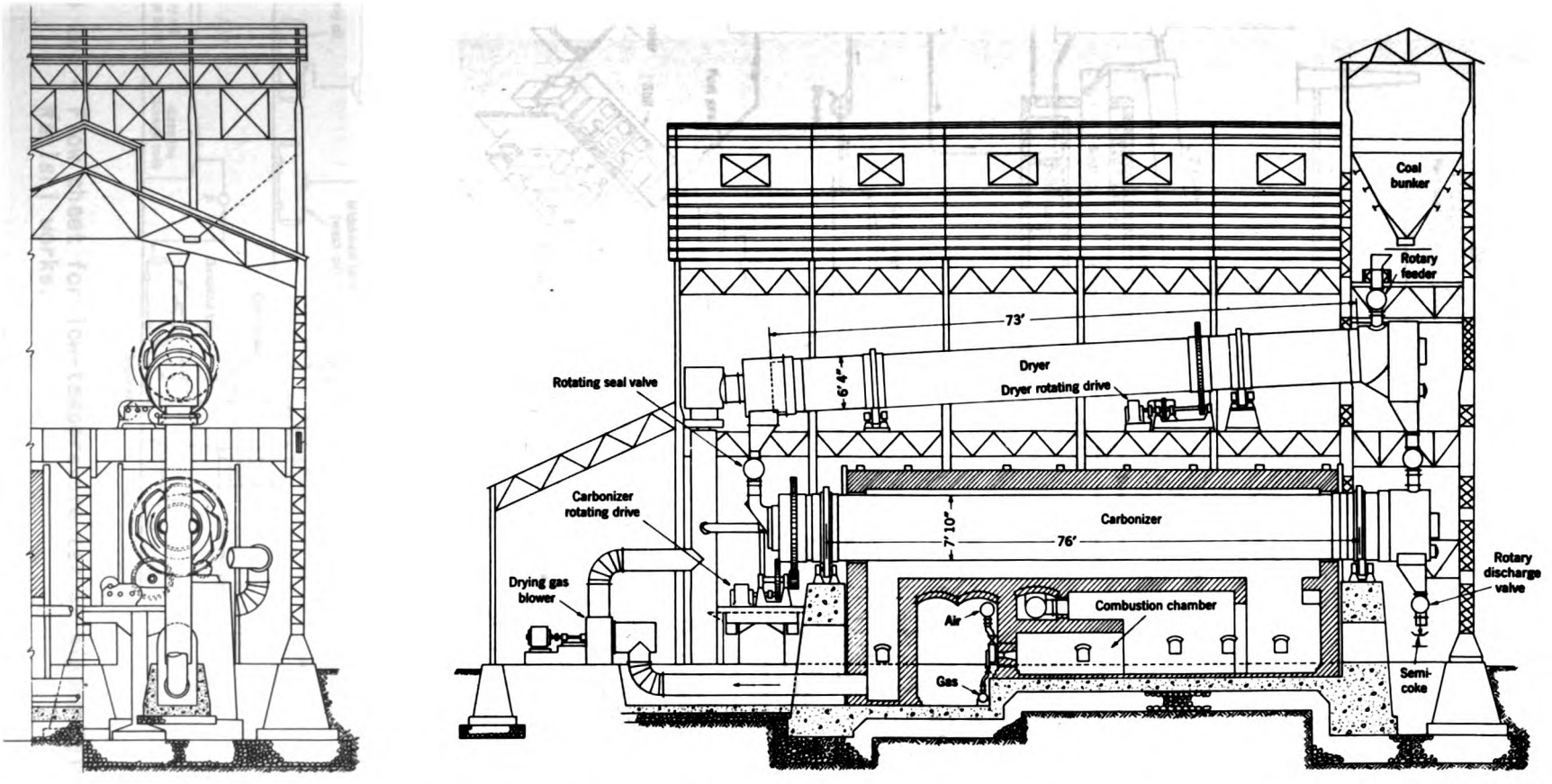

Figure 19. - Low-temperature carbonizer at Nippon Seitetsu K. K., Wanishi works.

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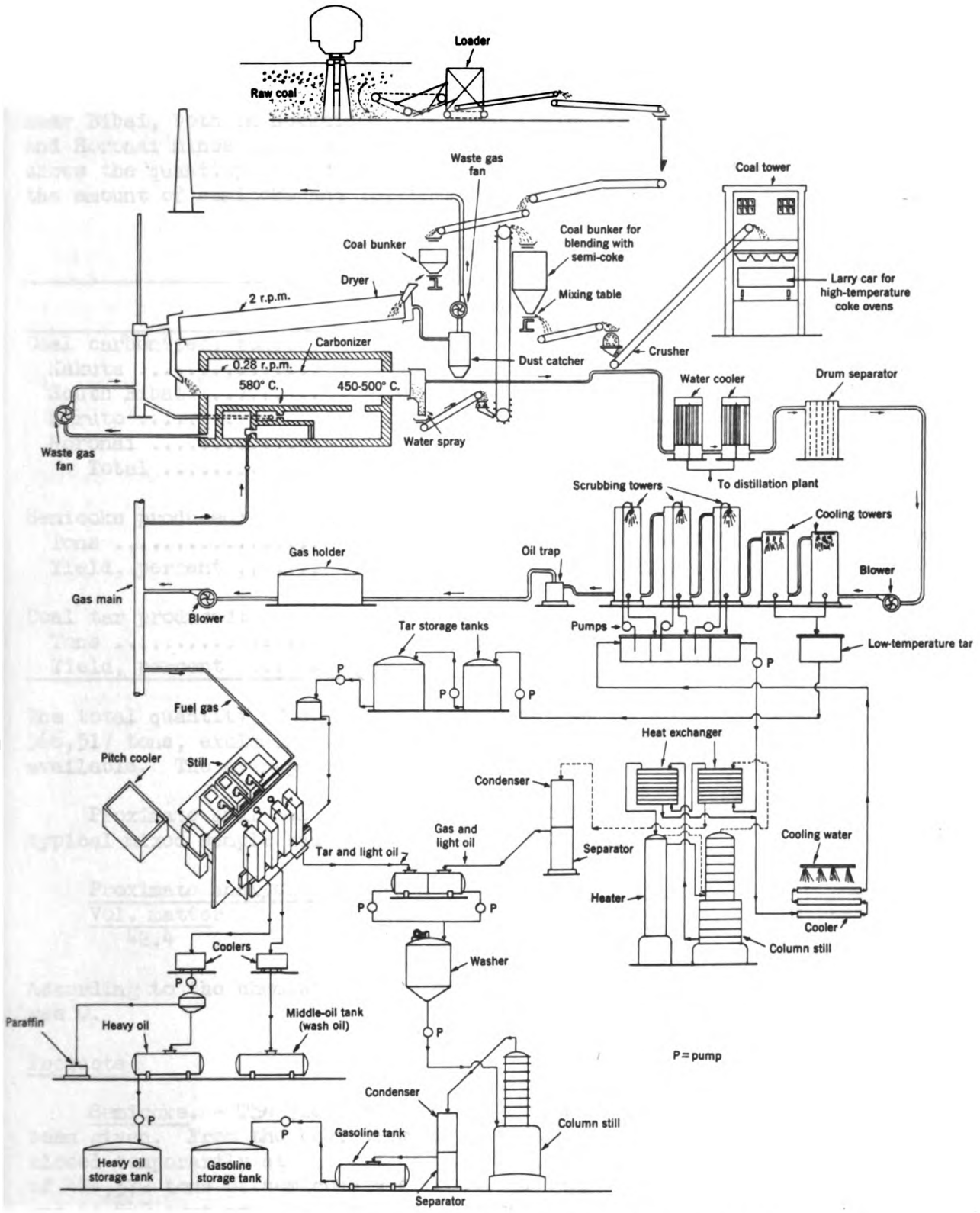

Figure 20. - Flow sheet for low-temperature tar at Nippon Seitetsu K. K., Wanishi works.

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required for blending was needed in sizes smaller than 3 mm., there was no necessity for carbonizing coal capable of producing lump semicoke. The source of the coal used in the low-temperature carbonizers was variable; that from the Kakuta mine in the Ishikari field and from the Miruto mine near Bibai, both in Hokkaido, were used ordinarily. Coal from South Bibai and Horonai mines also was used in small amounts. The following table shows the quantity of each coal used over a 6-month period during 1944, and the amount of semicoke and low-temperature tar obtained.

Coal used and yield of products

	1944						
	April	May	June	July	Aug.	Sept.	Total
Coal carbonized, tons:							
Kakuta	990	1,541	2,266	422	203	856	6,278
South Bibai	503	178	231	34	16	0	962
Miruto	1,772	1,643	587	515	255	504	5,276
Horonai	385	478	796	34	16	0	1,709
Total	3,650	3,840	3,880	1,005	490	1,360	14,225
Semicoke produced:							
Tons	2,738	2,880	2,910	754	368	1,020	10,670
Yield, percent	75.0	75.0	75.0	75.0	75.1	75.0	75.0
Coal tar produced:							
Tons	223	245	250	50	28	73	869
Yield, percent	6.1	6.4	6.4	5.0	5.7	5.4	6.1

The total quantity of coal carbonized since the erection of the plant is 566,517 tons, excluding 1938 and 1939 for which production data are not available. The average annual rate therefore is 70,814 tons.

Proximate analyses on each of these coals have not been made, but a typical mixed sample had the following composition:

Proximate analysis, percent, moisture-free basis			Calorific value,
Vol. matter	Fixed carbon	Ash	B.t.u./lb.
42.4	46.3	11.3	12,460

According to the chemists at the plant, the caking tendency of the mixture was 0.

Products

Semicoke. - The yield of semicoke for a typical 6-month period has been given. From the beginning of operation in 1936 until the plant was closed temporarily at the end of the war (excluding 1938 and 1939), a total of 424,372 tons of semicoke was produced. Thus the average annual output was 53,042 tons and the yield 74.9 percent. Maximum production was in 1943, with 79,073 tons of semicoke, equivalent to 240 tons per day for a 330-day year, or 80 percent of nominal capacity. The composition of a typical sample of semicoke is:

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Proximate analysis, percent, moisture-free basis			Calorific value,
Vol. matter	Fixed carbon	Ash	B.t.u./lb.
25.2	55.4	19.4	11,240

Semicoke for blending with high-volatile bituminous coal normally is considered best when the volatile-matter content is approximately 15 percent, but in this plant 25 percent volatile matter is preferred.

The effect of semicoke in a blend on the strength of the resultant coke is shown in figure 21. Yubari coal by itself produces a brittle, fingery coke and is not suited for use in blast furnaces because of its tendency to be crushed by the burden. Thus, for coke made from Yubari coal without admixture of other materials, the quantity of a sample retained on a 1/2-inch sieve is only 41 percent after the standard drum test. However, when 10 percent semicoke is blended with the Yubari coal before carbonization, the resultant coke is much stronger, 65 percent being retained on a 1/2-inch sieve after the same test.

During 1942, for blast furnaces of 1,000-ton capacity, it was necessary to use a blend containing 40 to 50 percent North China coal to obtain adequate coke strength. However, the coke at Wanishi during this same period usually was made from a blend of 70 percent Yubari coal, 15 percent North China coal, and 15 percent semicoke and was suitable for blast furnaces of intermediate size, that is, 500- to 700-ton capacity. The nature of the high-volatile coal used affects the strength of the resultant coke and fixes the quantity of semicoke required to obtain optimum results. In general, the addition of 10 percent semicoke is considered satisfactory. On this basis, the annual production of semicoke from this plant is sufficient to blend with approximately 477,000 tons of coal to yield about 318,000 tons of coke.

Liquid Fuels. - Only motor gasoline and bunker fuel oil were obtained as major products from the low-temperature tar. Their analyses and that of the tar are given below.

Properties of liquid fuels

	Coal tar	Motor gasoline	Bunker fuel oil
Specific gravity, 30° C.....	0.987	1/0.775	0.980
Flash point, °C.	80	ND	116
Neutral oil, percent	ND	99.5	70.8
Acidic oil, percent	ND	.5	27.8
Basic oil, percent	ND	Trace	.5
Distillation test, percent:			
0-170° C.	7	76	2
170°-235° C.	18	24	7
235°-270° C.	13	0	21
270°-350° C.	27	0	2/47
Residue	35	0	2/23

1/ At 15° C. 2/ Estimated. ND: No data available.

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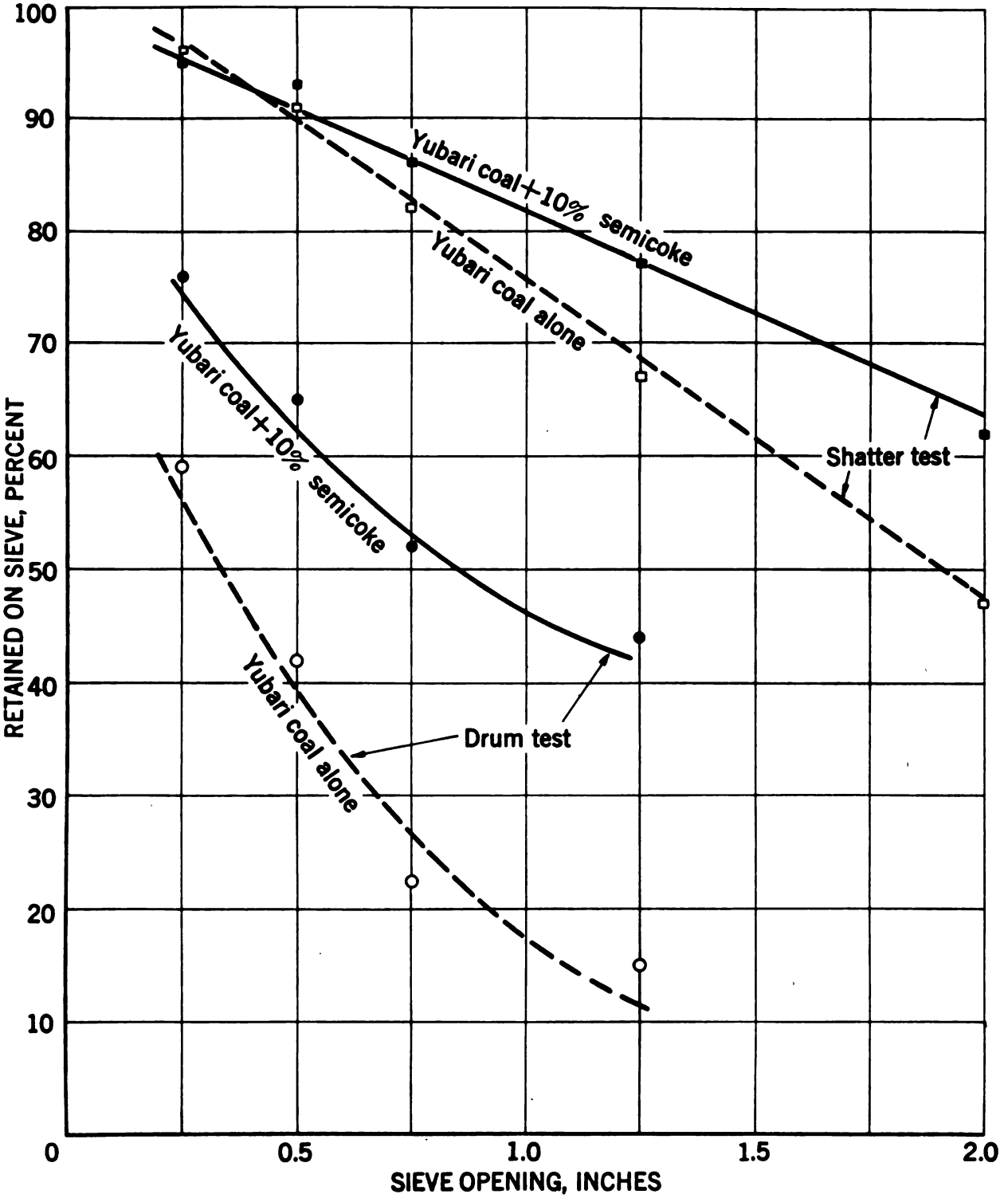

Figure 21. - Effect on the strength of the resultant coke of adding semicoke to Yubari coal.

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The yield of tar for the 6-month period tabulated above varied between 5.0 and 6.4 percent. Total production, including 1938 and 1939, was 35,676 tons, or 6.3 percent of the weight of coal carbonized. A greater yield would have been obtained had the volatile matter in the semicoke been reduced still further, but under the conditions of operation necessary to furnish a solid product containing 25 percent volatile matter, this yield of tar is considered satisfactory.

Data on the quantity of motor gasoline and bunker fuel oil produced were not available from the company but were furnished for the period 1940 to 1945 by Teikoku Nenryo Kogyo K.K. Total production for this period and its relationship to the quantity of coal carbonized follow:

Basis	Motor gasoline	Bunker fuel oil	Total
Kiloliters	3,169	11,723	14,892
Gallons, thousand	837	3,097	3,934
Tons	2,456	11,489	13,945
Percent by weight	17.6	82.4	100.0
Yield, percent of coal charged	.56	2.65	3.21

Although these yields of liquid products are small, they represent a reasonable amount, since the primary objective of this plant was the production of high-volatile semicoke.

Gas. - The composition of the gas obtained from the carbonizer is as follows:

Percent								Calorific value,
CO_2	O_2	H_2	CO	CH_4	C_2H_6	C_nH_{m2}	N_2	B.t.u./cu. ft.
12.0	0.3	4.2	7.5	33.1	16.5	10.6	15.8	787

The CO_2 and N_2 are both greater than in normal coke-oven gas, while the H_2 is much less. However, the calorific value is high because of the unusually large amount of CH_4 and higher hydrocarbons, resulting in a moderately rich gas. Data on the quantity of gas obtained were not available, but the volume required for heating the carbonizers is more than that made; thus it is necessary to supply some gas from an external source, in this case the high-temperature coke ovens at the same plant.

Present Status

The low-temperature carbonization plant suffered no war damage. Although none of the carbonizers were operating during June 1946, when the plant was inspected, all could have been placed in service immediately. Since these carbonizers are operated only to provide semicoke for blending, and as they require some coke-oven gas for heating, their operation is related closely to that of the high-temperature ovens. As these ovens are now largely out of service because of poor maintenance during the war and because coal is not available in adequate amounts, the immediate need for semicoke has largely been eliminated. Further, until the future status of the steel

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industry of Japan is clarified from the military standpoint, the coke industry also will be on an indefinite footing. If and when coke production is resumed at the Wanishi works, the low-temperature carbonization plant also will be placed in service, since, with postwar shortages in imported low-volatile coking coals, the importance of semicoke as a blending agent will be greatly enhanced.

DESCRIPTION OF PLANTS - KARAFUTO AND KOREA

General

No inspection could be made of plants not in Japan Proper, owing to limitations on travel outside the American occupation zone. However, many of the companies operating these plants under Japanese direction were controlled by Teikoku Nenryo Kogyo K.K., which furnished plant descriptions and production data. This information necessarily was incomplete but served to provide an adequate account of the low-temperature-carbonization industry outside Japan Proper but under Japanese ownership and control. Of interest is the fact that, during the period April 1940 to August 1945, liquid fuels produced by low-temperature carbonization plants in Japan Proper amounted to 203,069 KL (53.6 million gallons), whereas that from plants in Karafuto and Korea was 211,943 KL (56.0 million gallons), or 51 percent of the total. Each of the four plants described used Lurgi carbonizers.

Teikoku Nenryo Kogyo K.K. - Naifuchi works

Location

The plant was at Naifuchi, approximately due east of Naihoro, near the southern end of Karafuto, which is also called South Sakhalin.

Equipment

This plant was built in close proximity to the Naifuchi coal mine, which has an estimated output of 1,000,000 tons of coal per year. The primary objective of the plant was the production of liquid fuels; and, because the coal was weakly caking, the Lurgi system of low-temperature carbonization offered the best means of obtaining a satisfactory yield with a minimum of operating trouble. Two Lurgi carbonizers, each rated at 300 tons of coal per day, and two rated at 200 tons per day went into operation in December 1943. At the close of the war two more 300-ton units were 50 percent complete and two additional 200-ton units were 70 percent complete. When finished, therefore, the plant would have had a rated capacity of 2,000 tons per day, or 660,000 tons of coal per year, the largest under Japanese control.

The tar refinery was not completed in August 1945, but two tar pipe stills having a total capacity of 400 KL (105,672 gallons) of tar per day were in operation. The liquid fuels made consisted only of motor gasoline and bunker fuel oil. The gasoline refinery had a daily capacity of 50 KL (13,209 gallons).

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Coal and Products

The composition of the Naifuchi coal and of the semicoke made in the Lurgi carbonizer is:

	Proximate analysis, percent			
	Moist	Vol. matter	Fixed carbon	Ash
Coal	8.5	36.9	37.8	16.8
Semicoke	2.4	8.6	64.1	24.9

No analyses of the liquid products could be obtained.

Although the plant had not reached full production, engineering studies indicated that the yields would be about as follows:

Product	Expected yield, percent of coal carbonized
Semicoke	60
Crude tar	10
Crude gasoline	1
Motor gasoline	0.62
Gas oil	1.29
Semi-Diesel oil	3.90
Bunker fuel oil	1.32
Pitch	2.53
Paraffin	.38
Cresol	.12

As is usual with such plants, the actual recovery of semi-Diesel oil and bunker fuel oil may differ considerably from that expected.

For the period December 1943 to June 1945, the quantity of coal carbonized was 251,406 tons, as shown in table 15, a daily average input of 482 tons based on a 330-day operating year. Since the rated input of the plant was 1,000 tons per day during this period, it operated at 48.2 percent of capacity. The quantity of semicoke and of liquid products made during the same period is:

Basis	Semi-coke	Motor gasoline	Bunker fuel oil	Total
Kiloliters	-	1,732	26,920	28,652
Gallons, thousand	-	458	7,112	7,570
Tons	150,899	1,351	25,843	178,093
Yield, percent of coal charged	59.7	0.54	10.3	70.54

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TABLE 15. - Products from low-temperature carbonization of coal in Karafuto and Korea

Company and location	Process	Year[1]	Coal charged, tons[2]	Products									
				Semicoke, tons	Motor gasoline		Gas oil		Semi-Diesel oil		Bunker fuel oil		Liquid fuels, total	
					KL	Thousands of gal.	KL	Thousands of gal.	KL	Thousands of gal.	KL	Thousands gal.	KL	Thousands of gal.
Teikoku Nenryo Kogyo K.K., Naifuchi, Karafuto	Lurgi	1943	34,302	21,204	307	81	0	0	0	0	3,252	859	3,559	940
		1944	156,733	93,473	1,036	274	0	0	0	0	15,731	4,156	16,767	4,430
		1945	60,371	36,222	389	103	0	0	0	0	7,937	2,097	8,326	2,200
		Total	251,406	150,899	1,732	458	0	0	0	0	26,920	7,112	28,652	7,570
Teikoku Nenryo Kogyo K.K., Naihoro, Karafuto	Lurgi	1940	163,213	ND	950	251	608	161	0	0	7,225	1,909	8,783	2,321
		1941	223,951	123,166	2,415	638	2,158	570	1,552	410	7,878	2,081	14,003	3,699
		1942	242,127	133,169	2,558	676	2,086	551	8,285	2,189	2,399	634	15,328	4,050
		1943	261,816	143,998	2,829	747	2,350	621	9,831	2,597	2,916	770	17,926	4,735
		1944	220,677	ND	2,117	559	1,753	463	6,563	1,734	1,704	450	12,137	3,206
		1945	ND	ND	666	176	359	95	1,297	343	633	167	2,955	781
		Total	1,111,784	400,333	11,535	3,047	9,314	2,461	27,528	7,273	22,755	6,011	71,132	18,792
Chosen Jinzo Sekiyu K.K., Agochi, Korea	Lurgi	1940	ND	ND	240	63	1,300	343	ND	ND	8,300	2,193	9,840	2,599
		1941	ND	ND	350	92	1,850	489	ND	ND	12,400	3,276	14,600	3,857
		1942	ND	ND	480	127	2,600	687	ND	ND	16,600	4,385	19,680	5,199
		1943	ND	ND	360	95	1,900	502	ND	ND	12,000	3,170	14,260	3,767
		1944	ND	ND	240	63	1,300	343	ND	ND	8,300	2,193	9,840	2,599
		1945	ND	ND	140	37	760	201	ND	ND	4,800	1,268	5,700	1,506
		Total	ND	ND	1,810	477	9,710	2,565	ND	ND	62,400	16,485	73,920	19,527
Nippon Chisso Kogyo, K.K., Kian, Korea	Lurgi	1942	ND	ND	194	51	356	94	2,079	549	1,995	527	4,624	1,221
		1943	ND	ND	128	34	382	101	3,251	859	ND	ND	3,761	994
		1944	ND	ND	55	15	110	29	20	5	747	197	932	246
		1945	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
		Total	ND	ND	377	100	848	224	5,350	1,413	2,742	724	9,317	2,461

1/ Fiscal year, Apr. 1-Mar. 31.
2/ Ton, metric = 2,205 lb.
ND: No data available.
Source: Teikoku Nenryo Kogyo K.K.

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Costs

The total cost of this plant was stated to be ¥131,035,462, including the coal mine and associated property. Since a large part of the plant was still under construction, the cost per ton of installed capacity cannot be computed, but the investment costs are much greater than in any other plant for which cost data were obtained.

Present Status

As this plant has not been accessible since the end of the war, no information is available on its present status. When left by the owners, the plant was in working condition, and all equipment was in good order.

Teikoku Nenryo Kogyo K.K. - Naihoro works

Location

This plant was located at Naihoro, on the west coast of Karafuto, approximately 50 miles north of the southern tip of the peninsula.

Equipment

Originally built and operated by the Mitsubishi Sekitan Yuka Kogyo K.K., erection of this plant was begun in 1934. Initial operation was in 1935. Two Lurgi low-temperature carbonizers, rated at 150 tons of coal per day, were the first installed in Japan and were built with the assistance of German engineers furnished by Lurgi-Gesellschaft, from which the patent rights and engineering data were obtained. All the equipment, with the exception of the exhauster fan, was made in Japan. In 1937 the plant was expanded with the construction of two more Lurgi carbonizers each rated at 200 tons of coal per day, thus increasing the total daily plant capacity to 700 tons. Later the company was absorbed by Teikoku Nenryo Kogyo K.K., placing the plant under Government control.

The tar recovery and refining system was the same as for later Lurgi carbonizers, except that cyclone dust separators were used in place of the Cottrell precipitator, which had not yet been developed to a satisfactory state.

Operating troubles included clogging of the gas distributors with coal dust, thus decreasing the actual capacity of the 150-ton carbonizer to only 100 tons of coal per day. Later it was found that injecting steam into the combustion chamber of the carbonizing section increased the gas volume to the point where the distributors were swept clean, thus increasing the capacity to 180 tons per day. There is no indication that other plants operating Lurgi carbonizers in Japan have used this scheme to keep the distributors from becoming clogged. Corrosion of the gas mains by sulfur corrosion was severe; there was no provision in the design for removing sulfur from the gas burned in either the drying or the carbonizing sections.

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Coal and Products

Coal was obtained from the Naihoro mine near the plant. Its size was 2 inch by 3/8 inch and its proximate analysis and that of the semicoke were:

	Proximate analysis, percent			
	Moist	Vol. matter	Fixed carbon	Ash
Coal	14.0	41.0	37.1	7.9
Semicoke	.6	6.6	77.6	15.2

Although no measurement of caking index was made, the coal is considered noncaking.

Predicted performance, based on the coal and the expected action of the carbonizers was as follows:

Product	Expected yield, percent of coal carbonized
Semicoke	55
Crude tar	9.3
Crude gasoline	1.2
Motor gasoline	.85
Gas oil	.78
Semi-Diesel oil	3.02
Bunker fuel oil	.79
Pitch	2.33
Paraffin	.27
Cresol	.23

These yields are considerably different from those expected at the Naifuchi plant, the principal difference being an increase in gasoline and a decrease in bunker fuel oil. Because actual production may be considerably different from that predicted, particularly in the distribution of liquid products, these data are of limited value.

The quantity of coal carbonized since the plant started in 1935 is 1,563,361 tons; thus it has a larger total production than any other plant on which data have been obtained. Information is sketchy on the quantity of semicoke produced and of liquid products obtained; for the period 1940 to 1945, when 1,111,784 tons of coal was carbonized, the products were as follows:

Basis	Semicoke	Motor gasoline	Gas oil	Semi-Diesel oil	Bunker fuel oil	Total
Kiloliters	-	11,535	9,314	27,528	22,755	71,132
Gallons, thousand	-	3,047	2,461	7,272	6,011	18,791
Tons	1/611,481	9,113	8,196	25,876	21,845	676,511
Yield, percent of coal charged	55.0	0.82	0.74	2.33	1.96	60.85

1/ Estimated, based on 55 percent yield.

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No analysis was available on the excess gas obtained from the Lurgi carbonizer, but it was stated to have a calorific value of 278 B.t.u. per cubic foot, considerably higher than other Lurgi carbonizers. The volume of cooling gas entering the carbonizer for each ton of coal carbonized is 31,800 cubic feet.

Costs

Total investment in the Naihoro plant was ¥28,116,942. For a rated annual capacity of 231,000 tons of coal this represents an investment charge of ¥122 per ton of capacity per year.

Present Status

Like the Naifuchi works, no information has been received from the plant since the end of the war. So far as is known, all the equipment was in operating condition in August 1945.

Chosen Jinzo Sekiyu K.K. - Agochi works

Location

Haigando 50, Agochi-yu, Keiko-tun, Kankyohokudo, Korea.

Equipment

Four Lurgi carbonizers, each having a capacity of 150 tons of coal per day, have been in operation at this plant, while three more of the same size were under construction at the end of the war. In addition to low-temperature carbonization, a synthetic methanol plant was in operation, and a hydrogenation plant had been built. Hydrogenation of coal, however, was still in an experimental stage, and commercial production was never attained, the output at most being 100 KL (26,418 gallons) of gasoline per year. Methanol production was more satisfactory, an estimated 13,000 KL (3.4 million gallons) being made in 1944, of which 90 percent was furnished to the Army Fuel Board and the Naval Office of Accounts and Supplies. According to the engineers, this methanol was used largely as fuel for internal-combustion engines of expendable aircraft of the "kamikaze" type.

Coal and Products

No analyses of the coal used in this plant are available; it was obtained from the nearby Agochi mine and from the Shora mine, the exact location of which could not be determined. The entire plant used approximately 600,000 tons of coal per year and produced an estimated 140,000 tons of semicoke. Exclusive of methanol, production of liquid fuels reached a maximum in 1942, with 19,680 KL (5.2 million gallons) shipped. During the period 1940 to 1945, as shown in table 15, a total of 73,920 KL (19.5 million gallons) of liquid fuel was produced; 27,000 KL (7.1 million gallons) of methanol was made during this same period.

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Costs

The capital investment in the entire plant was stated to be ¥90,000,000 but no information is available on the distribution of costs.

Present Status

Like other plants in this zone, no information could be obtained on the present condition of the equipment. The Tokyo office of Nippon Chisso Hiryo K.K., half owners of the company, have had no contact with the plant since the termination of the war.

Nippon Chisso Kogyo K.K. - Eian works

No detailed information could be obtained on this plant, but it was understood to be equipped with Lurgi carbonizers first operated in 1942. Production was small, only 9,317 KL (2.5 million gallons) of liquid fuel being made in the period between 1942 and the end of the war.

DESCRIPTION OF UNCOMPLETED PLANTS

General

Increasingly serious shortages in liquid fuels as the war progressed stimulated interest in low-temperature carbonization, as such methods were found in general to give little trouble in operation even through the yield of liquid products per ton of coal was not as high as for Fischer-Tropsch synthesis. However, many of the planned installations were never completed, either because they were poorly conceived, or because of lack of materials and manpower. Four of these plants were situated in Hokkaido and one in Manchuria; those in Hokkaido were inspected, the information reported being based on personal observation. Data on these plants is given in table 5.

Nihon Nenryo Kogyo K.K.

This company was founded in Iwamizawa, Hokkaido, in 1937, with a capitalization of ¥2,000,000. The objective was to construct a plant for the low-temperature carbonization of coal, but except for the purchase of a plant site of 8 acres, no further work was done. An internally heated carbonizer was being considered in which coal would pass countercurrent to the flow of hot gases, the coal moving over and through a series of rotating horizontal trays stacked in a vertical cylindrical steel retort. No detailed plans of the carbonizer had been prepared, nor had an experimental unit been constructed, and it is unlikely that this company will attempt to construct a working plant.

Nippon Jinzo Sekiyu K.K. - Takikawa works

Originally incorporated as the Hokkaido Jinzo Sekiyu K.K. in December 1938 with a capitalization of ¥70,000,000, a plant for the production of synthetic liquid fuels by the Fischer-Tropsch process was begun by this

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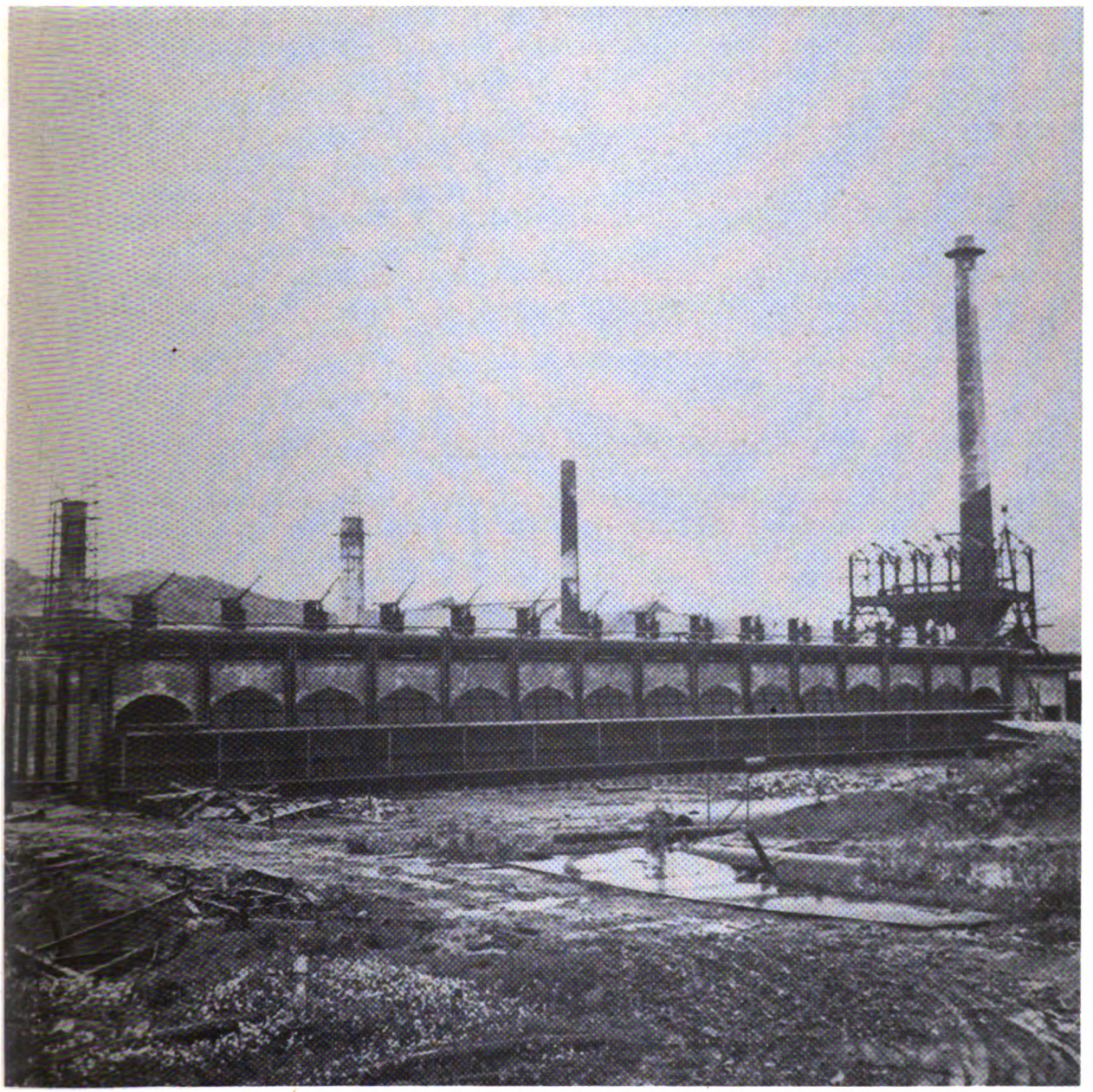

Figure 22. - Uncompleted battery of Knowles ovens at Hokkaido Tanso Kogyo K. K., Hiragishi, Hokkaido.

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company in June 1939. Trial operation was started in December 1942, but unexpected difficulties delayed regular production until April 1944. In October 1944 the company was incorporated with others to form the Nippon Jinzo Sekiyu K.K., with a capitalization of ¥150,000,000. Difficulties in operating the synthesis-gas process and unexpectedly low yields caused by unsatisfactory catalyst performance resulted in the decision to construct a low-temperature carbonization unit to increase the plant output of liquid fuels, and an installation of Knowles ovens was planned. Construction of 2 batteries, each with 30 ovens, was begun in March 1945. The ovens were to be of standard size, 40 feet long and 9 feet 9 inches wide, with a capacity of 7 tons of coal per charge, and thus would be identical with those built in 1940 by Nihon Yuka Kogyo K.K. at Kawasaki, which furnished details of the design. Termination of the war stopped construction; the foundations for all 60 ovens were completed, but brickwork on only 15 ovens had been started and was about 35 percent finished. Lacking information on future policies regarding such plants, no decision has been reached by the company concerning the completion of these ovens.

Nippon Jinzo Sekiyu K.K. - Rumoi works

Like the Takikawa works, this plant had belonged originally to Hokkaido Jinzo Sekiyu K.K., and, as part of the over-all plan for production of synthetic liquid fuels, was to have operated a Fischer-Tropsch synthesis plant on gas made by Fiag gas generators and Lurgi complete gasification equipment. The six Fiag generators were expected to have a total daily capacity of 600 tons of coal and were to have been operated with recovery of tar for byproduct processing. Because of the similarity of the tar to that obtained from low-temperature carbonization processes, this equipment was considered in that classification, although all the semicoke produced was to be gasified within the generator. Construction of this plant was delayed because of lack of material, the Takikawa works being given a priority on available equipment, thus construction did not proceed beyond the foundation stage and the Fiag generators had not been manufactured. Future plans call for abandoning the intended liquid-fuels plant and converting the existing buildings and equipment to the processing of fish products for fats and oils as well as food. A proposed merger with the Hokkaido Suisan Gyokai to form the Hokkaido Suisan Kagaku Kogyo K.K. would supply the necessary funds.

Hokkaido Tanso Kogyo K.K. - Hiragishi works

This plant is situated at Hiragishi, Sorachi-gun, Hokkaido. Originally belonging to Nihon Yuka Kogyo K.K. and known as the Sorachi Works, the plant was to be constructed in Hokkaido because of its proximity to large deposits of coal. Preliminary plans called for the construction of 120 Knowles ovens of standard size, with a capacity of 540,000 tons of coal per year, expected to produce 360,000 tons of semicoke and 36,000 tons of coal tar annually. Although construction was begun in October 1944, none of the ovens were actually built, only temporary construction shops being finished by August 1945.

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In January 1944, Hokkaido Tanso Kogyo K.K. was formed with a capitalization of ¥10,000,000, with Nihon Yuka Kogyo holding 10 percent of the stock. Construction of a plant began immediately on the same site planned for the Knowles oven installation of Nihon Yuka Kogyo K.K., thus the Hiragishi works and the Sorachi works coexist and constitute a single plant. The objective of Hokkaido Tanso Kogyo K.K. was to produce electrode carbon by the carbonization in Knowles ovens of a creosote extraction of coal; this extract would be reliably free of ash and thus would be a substitute for coal-tar pitch. An installation of 15 Knowles ovens was begun for this purpose; the ovens were 90 percent complete in August 1945 (see fig. 22). The intended production of electrode carbon was relinquished at the end of the war, the future intention of the company being to complete the 15 Knowles ovens to produce semicoke and liquid fuels. Financial considerations and lack of manpower and materials may prevent the carrying out of this plan.

Manshu Jinzo Sekiyu K.K. - Chielin works

This plant, located in Chielin, Manchuria, was to have produced methanol synthetic liquid fuels by the Fischer-Tropsch process, and liquid fuels from low-temperature tar obtained by the Lurgi process. The company was capitalized at ¥50,000,000, with Teikoku Nenryo Kogyo K.K. holding 35 percent of the stock. The four Lurgi carbonizers, of which two were completed, were each rated at 150 tons of coal per day, thus the final installed daily capacity of the plant would have been 600 tons. By August 1945 construction of the plant had not been completed to the point where production could begin. Its present status is unknown.

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